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SCIENTIFIC DIRECTOR'S REPORT

ANNEX 2.7

THERMAL-RADIATION INJURY

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Annex 2.7

Thermal-radiation Injury

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THERMAL-RADIATION INJURY

by

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Abstract

Information concerning the flash burn resulting from an atomic bomb explosion was necessary to understand the lesion, its systemic effects, and prevention and treatment of these effects. In order to reproduce similar sources in the laboratory it was essential to know the characteristics of the energy producing the biological effect. In order to obtain this information, anesthetized experimental animals were placed in shielded positions at varying distances from bomb zero to cover a wide range of thermal-radiation intensities. Small areas of each animal's skin were exposed through aperture plates which were designed to analyze burn production as a function of time, intensity, and spectrum. Protection of the animal by fabrics covering the skin was also evaluated. In each station, calorimetric instruments measured the thermal energy to which the animals were exposed. These measurements were of total integrated energy and that in the spectral ranges of 2,500 to 4,000 A, 4,000 to 8,000 A, and 6,000 to 27,000 A. Following exposure, animals were retrieved from the exposure stations and transported to a laboratory for analysis of the burn lesions by description, color photography, and microscopic study of biopsy material.

Chapter 1

Introduction

The primary burn from an atomic bomb explosion is caused by a brief exposure to high-intensity radiant energy, whereas the usual burn seen in ordinary life is from contact with lower temperatures. How much difference this creates in the local lesion, its systemic effect, clinical course, and mortality is not known.

Tsuzuki [1] stated that 90 per cent of the Japanese who sought aid in the first week after the atomic bombing did so because of thermal burns. In Hiroshima alone, there were approximately 70,000 cases of burns of which about 40,000 were serious. This created an enormous problem of clinical management which could not be satisfactorily handled. There is not yet a practical plan for the immediate mass treatment of so many burn casualties.[2][3] The first requisite of rational therapy is to understand the lesion to be treated. Hence, the first step toward the solution of the problem of the mass management of flash burns from the atomic bomb was knowledge of the characteristics of this injury.

In spite of the thousands of flash burns at Hiroshima and Nagasaki, there was not a single immediate biopsy available to illustrate the histological changes produced in the skin.

This was understandable in view of the confusion and difficulties created, but it did not permit a clear picture of the lesion in man. Many histological sections from Japanese casualties were reviewed but all were obtained late after infection or repair had set in. Likewise, at the Bikini tests, emphasis was focused on the effect of ionizing irradiation on the animals exposed, so here again no immediate skin biopsy of thermal burns could be found. Thus, the investigator who attempted to reproduce, in the laboratory, the flash burn from the atomic bomb did not know whether or not the experimental method achieved its aim.

In the laboratory, skin biopsies of the flash burns in experimental animals showed a proportionality existing between the depth of injury and amount of energy applied.[4]-[6] It was necessary to evaluate, in the field, the relation of the intensity of the thermal energy from an atomic bomb to the severity and depth of the burn. This would define the burn as a function of energy.

Time dependence of burn production from the atomic bomb explosion was a matter of dispute which was argued on theoretical grounds. There were no data from observation of burning as a function of time after the explosion. In the manual, *The Effects of Atomic Weapons,*[7] Fig. 6.6 showed an initial

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[1] M. Tsuzuki, "Report on the Medical Studies of the Effects of the Atomic Bomb," *General Report, Atomic Bomb Casualty Commission* (Washington: National Research Council, 1947), Appendix 9.

[2] E. I. Evans, "The Burn Problem in Atomic Warfare," *Journal of the American Medical Association,* CXLIII (1950), 1143.
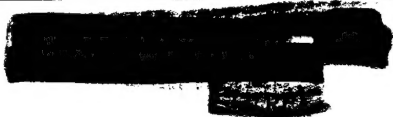
[3] H. E. Pearse and J. T. Payne, "Mechanical and Thermal Injury from the Atomic Bomb," *New England Journal of Medicine,* CCXLI (1949), 647.

[4] H. E. Pearse, J. T. Payne, and L. Hogg, Jr., "The Experimental Study of Flash Burns," *Annals of Surgery,* CXXX (1949), 774.

[5] L. Hogg, Jr., J. T. Payne, and H. E. Pearse, "Experimental Flash Burns: The Pathologic Aspects," *Archives of Pathology,* XLIX (1950), 267.

[6] Greenhouse Report, Annex 2.2, Part IX, Sec. 1.

[7] *The Effects of Atomic Weapons* (Washington: U. S. Government Printing Office, 1950).

high intensity which dropped to a minimum of approximately 2,000°K in about 15 msec. A short lull was followed by a rise to a second maximum of about 7,000°K in 0.3 sec, after which the temperature fell. Nearly all the thermal radiation was emitted in 3 sec and had ceased by 10 sec after bomb detonation.

The initial flash attained a very high temperature but lasted only 15 msec. Because of this short duration, only 1 per cent of the total thermal energy was delivered in this period. Yet it was thought by some that, due to the high temperature and high ultraviolet content, flash burns occurred in this stage. One fact which argued against this was the lack of corneal burns in the Japanese. The blink reflex requires between 10 to 15 msec, so it was assumed that the eye was open in this initial period but covered by the eyelid thereafter, preventing a burn of the cornea. This was not reliable evidence, so the question of serious burning in the initial period required experimental study. A shutter was devised which closed one port and opened another during the lull following the initial flash. When an animal was placed behind this shutter, one area of skin was exposed during the initial flash and a second area during the subsequent ball of fire.

As previously noted, the second maximum occurred in about 0.3 sec and the majority of the radiation from the ball of fire in 3 sec. It was necessary to determine when flash burns occurred in this period at different distances from the explosion. This information might show whether or not evasive action by exposed personnel was effective.

The influence of thermal energy of various regions of the spectrum on the production of flash burns from the atomic bomb was not known. The depth of penetration varied directly with wave length, ultraviolet being the least and infrared the most penetrating. In addition to pure thermal injury, ultraviolet had a photochemical effect which reached a maximum at 2,970 A. Wave lengths below 1,900 A were absorbed by ozone. Atmospheric attenuation was greatest for the shorter wave lengths, so it was probable that they could be disregarded at the distant perimeters. By the use of appropriate filters over the exposure ports, the importance of energy from various regions of the spectrum could be evaluated.

The thermal energy released by the bomb explosion might be modified by nitrogen dioxide, ozone, atmospheric opacity to short wave lengths, scattering, absorption, and other attenuating factors. This might make extrapolation difficult, so it was desirable to measure at each station the total integrated energy and that passing through the filters. This was done in such a way that the calorimetric instruments were exposed in exactly the same manner as the exposed areas of the animals' skin. Thus, the energy responsible for the burn could be determined.

It was well known from observations made upon the Japanese that the color, thickness, and composition of clothing influenced the burn received. A suitable garment might protect the skin from injury by thermal radiation of sufficient intensity to cause a burn of the exposed skin. The thermal properties of many fabrics had been studied in the United States Naval Material Laboratory and were tested in Project 6.2 experiments, where the thermal transmission of fabrics was measured by inanimate substances such as wax. This, at least to the clinician, did not give as complete assurance of its protection against burns as would the use of biological testing material. At the request of the Office of the Surgeon General, U. S. Army, fabrics to be used for uniforms were tested for their protective effect on animal skin.

Chapter 2

Methods

2.1 ANIMALS

Young Chester White pigs, Danish Landrace pigs, and adult foxhounds were clipped, placed in containers, transported to exposure stations, anesthetized, and positioned behind individual exposure plates in structures appropriately constructed to withstand blast and to minimize effects of ionizing radiation. For Shot Easy, 39 Chester White and 8 Danish Landrace pigs and 15 dogs were thus prepared. For Shot George, 20 white pigs were used. Some of the unburned pigs from distant stations in Shot Easy were re-used in Shot George.

It was originally proposed that all pigs used be Chester Whites. Due to a shortage of animals of this breed in the Forward Area, it was necessary to use some Danish Landrace pigs which were a mixed brown and black in color.

Animals were well acclimatized to the Forward Area, for all the pigs and some dogs were born and reared there, and the remaining dogs were kept for many months at Site L.

2.2 ANESTHESIA

Animals were anesthetized with intraperitoneal injections of Dial in urea-urethane (Ciba) in doses of 75 mg of Dial per kilogram of body weight for pigs and 60 mg of Dial per kilogram of body weight for dogs. This drug and its dosage were selected after extensive tests which are recorded in another report.[1] After induction of anesthesia, one side of each animal was clipped closely before positioning in the exposure container.

2.3 EXPOSURE CONTAINERS

These containers for holding the individual animals were spring-loaded in order to hold the animal against the aperture plates in the protective shelters. Complete description of the containers, transporting liners, and pallets is found in another report.[2]

2.4 EXPOSURE OF ANIMALS

The precise locations of the thermal stations were critical, for in this study a variation of a few calories was important. For example, threshold studies (Annex 2.2, Part IX, Sec. 1) indicated that 3 cal/cm^2 in 1 sec applied to the pig's skin gave only persistent erythema, while 5.5 cal/cm^2 in 1 sec caused surface coagulation. There were several difficulties in obtaining such exact exposures in the field. First, the stations had to be placed on available islands, which were not always at the distances desired. Next, the factors responsible for atmospheric attenuation were variable and the methods of scaling were not uniform, so exact calculation of the thermal energy expected at any given location was impossible. Finally, the yield in Shot Easy was changed after the stations were located, and that in Shot George was uncertain with a possible variation of 100 kt. It was evident that under these circumstances, the best position of thermal stations could only be approximated after consideration of the several variables mentioned. The final locations of stations are given in Tables 2.1 and 2.2. Of these, all stations were used for Shot Easy but only the first two stations were operated for Shot George.

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[1] Greenhouse Report, Annex 2.2, Part IX, Sec. 2.

[2] Greenhouse Report, Annex 2.2, Part IX, Sec. 4.

TABLE 2.1 LOCATION OF THERMAL STATIONS—SHOT EASY

STATION	SITE	DISTANCE (yd)	TOTAL INTEGRATED ENERGY[a] (cal/cm²)	
			20 Kt (Original Estimate)	50 ± 10 Kt (Final Estimate)
75	E	1,325	57	125
76	S	2,270	18	45
77	T	3,109	9.6	24
78	T	3,500	7	18
78a	Sandspit	4,508	4	11
79	P	5,664	2.2	5.5

[a] Using formula of P. Harris in LASL Document SD–1861 (Lab–J–976), 1950.

TABLE 2.2 PREPARED LOCATION OF THERMAL STATIONS—SHOT GEORGE

STATION	SITE	DISTANCE (yd)	TOTAL INTEGRATED ENERGY[a] (cal/cm²)	
			150 Kt (Minimum Yield)	250 Kt (Maximum Yield)
75	R	3,460	54	90
76	N	4,785	26	43
77a		±6,000	15	25
77b		±8,000	7.4	12
78	C	±9,700	4.5	7.5
79	C	12,490	2.1	3.5

[a] Using formula of P. Harris in LASL Document SD–1861 (Lab–J–976), 1950.

2.5 SHELTERS AND APERTURE PLATES

The construction of the thermal exposure stations was described in detail in Annex 2.2, Part IX, Sec. 4. Stations were designed to give adequate protection against calculated overpressure from the blast and to minimize the effects of ionizing irradiation on the contained animals. In Shot Easy, each of the five stations provided thermal exposure to eleven animals and one set of instruments. In the side of the station facing the bomb burst there were six ports. Behind these ports were bolted two heavy aluminum plates with apertures through which thermal radiation passed. Two animal containers, one above the other, were bolted to the back of the port in such a manner that the flanks of the exposed animals were in contact with the apertures. The stations were ventilated with battery-operated blower and duct systems as described in Annex 2.2, Part IX, Sec. 4. These had been tested and provided adequate ventilation for survival of the enclosed animals. The proposed stations for Shot George were similar except for the size of two portable stations (77a and 77b). Each of the latter had four ports instead of six and contained seven animals and one set of instruments.

The exposure aperture plates were of three types, each constructed of ¾-in. aluminum alloy, 6 by 12 in. in size. All openings in the plates were covered by fused-quartz windows to eliminate sandblasting of the skin subjected to the explosion. Each of the three plates had one aperture which was not modified by a shutter or a filter so that each animal received the total integrated energy on one area of skin as a control for those modified by filters or shutters. The three types of plates were as follows:

(a) *Fast Shutter Plate*. This plate had three round apertures. One was 2.2 in. in diameter and provided the unmodified exposure. The two remaining apertures were 1.125 in. in diameter. At the time of the flash from the explosion, one of these ports was open and the other was covered by a spring-loaded aluminum shutter. The shutter was timed to cover the open port and open the closed one in 20 to 25 msec. This was planned to give an evaluation of the burn produced by the initial flash in comparison to that from the ball of fire.

(b) *Slow Strip Shutter Plate*. This plate contained one rectangular aperture, 2 by 8 in. in size, placed horizontally. A quartz window covered the entire area. Behind the window was a thin sliding shutter which had an opening 2 by 5 in. Travel of the sliding shutter was initiated by the blue-box signal. Transport time for the shutter was 2 sec. By this

method, 3 in. at one end of the rectangular opening in the plate was closing and 3 in. at the other end was opening during the 2 sec following the initiation of the explosion. The central 2 in. was open throughout the exposure. Provision was thus made for assessment of the burn as a function of time after explosion.

(c) *Filter Plate.* This plate had four round apertures. One of these was 2.25 in. in diameter and had only the clear-quartz window covering it. The other three openings were 1.375 in. in diameter and were covered by optical filters which are discussed below. A complete description of these filters appears in another report.[3]

2.6 INSTRUMENTATION

The thermal energy received by the experimental animals was measured at each station for both shots. The total energy incident on a unit of area at various distances from the bomb was measured, and the energy was determined in three spectral regions: 2,500 to 4,000 A, 4,000 to 8,000 A, and 6,000 to 27,000 A. The physical arrangement of the instruments in the animal stations was such that the instrument was exposed in exactly the same way as the animals' skin. A detailed discussion of the instrument and its theory is found in University of Rochester Atomic Energy Project reports [4] [5] and in Annex 2.2, Part IX, Sec. 3.

The aperture assembly consisted of ¾-in.-thick aluminum plate, designed to protect the instrument from blast effects. The openings in the aluminum plate which provided the limiting aperture for thermal radiation were circular with an area of 1 cm² and were protected by fused-quartz windows 7/16 in. thick.

[3] Greenhouse Report, Annex 2.2, Part IX, Sec. 3.

[4] R. M. Blakney *et al.*, "Development of Copper Sphere Radiometer," UR 152 (Rochester, N. Y.: University of Rochester Atomic Energy Project, 1951), p 76.

[5] H. D. Kingsley *et al.*, "Biological Effects of External Radiation," UR 96 (Rochester, N. Y.: University of Rochester Atomic Energy Project, 1949), p 35.

The filters used for the infrared measurement were Corning No. 2404, Sharp Cut-Off Red Glass. For the visible region, Pittsburgh Heat-absorbing Glass was found to be the most satisfactory because it had no transmission band outside its main spectral region. For the ultraviolet filter, it was found necessary to use a combination of 60 per cent aqueous solution of nickel sulphate and the Corning No. 9863 glass for two reasons: first, the No. 9863 glass tended to crack with moderate temperature changes, and second, both the No. 9863 glass and the nickel sulphate solution had minor transmission bands in the visible which the combination eliminated. The solution performed the added function of providing a filter with a large heat capacity which absorbed most of the energy, leaving very little work for the No. 9863 glass to do.

The measuring instrument consisted of a metal container with four openings in the front plate which was placed against the back surface of the aperture plate. Within the container were four radiation receivers, one behind each opening. The individual receiver was composed of a thin-walled copper sphere 5 cm in diameter, blackened on the inside. A single circular opening in the sphere was slightly larger than the aperture in the front plate with which it was aligned. Behind the receiving sphere and thermally isolated by a double-walled compartment was a second, similar, reference sphere. This pair of spheres constituted a measuring unit and to each sphere in the unit was attached a thermistor. Each thermistor made up one arm of a modified Wheatstone bridge at the back of the instrument. In addition to the four radiation-measuring units, there was a fifth unit, the function of which was to measure the temperature of the instrument housing.

In general, the method of measurement was calorimetric. Radiation entered a sphere through the opening and was absorbed by the wall, raising its temperature. The thermistor attached to the receiving sphere was in one arm of the Wheatstone bridge, and the thermistor attached to the compensating sphere in

the back row was in the other arm. Before exposure, each sphere in the front row was assumed to be at the same temperature as its reference sphere in the back row. The thermistors were so matched that, when this condition prevailed, the bridge was balanced and would stay balanced over a range of 10°C. The change in temperature of the receiving sphere after the shot was recorded as an unbalanced voltage across the bridge.

Each instrument fed the information from the four Wheatstone bridges connected with the spheres and the one connected with the case to a Leeds and Northrup Speedomax Six-Point Recording Potentiometer which had a response time of 1 sec for a full-scale deflection and a printing time of 2 sec per point. In the field, the power for the recorder was supplied by a motor-generator set which operated from 24 v dc and supplied 110 v ac at 0.5 kva. (A description of the electrical circuit at each station and the power connections was given in Annex 2.2, Part IX, Sec. 4.) One-half hour before shot time, the power was turned on by the —30 min timing signal to allow the recorder amplifier to warm up. After the shot, the equipment was allowed to run until the animals were retrieved so that a full record of the temperature as a function of time was obtained. At the stations where the —30 min timing signal was not available, the warm-up

period was initiated by a mechanical timer with an 8-day spring-driven movement.

The calculation of the energy received by the sphere involved the measurement of the area under the temperature-time curve, which could be shown to be proportional to the energy received.

2.7 PROTECTIVE EFFECTS OF FABRICS

In Shot Easy, two filter plates, in Stations 78, 78a, and 79, respectively, were modified to test the protective effects of material provided by the Philadelphia Quartermaster's Depot. In Shot George, fabrics replaced two filter plates in Station 75 and two in Station 76. The quartz shield was left in place, but six optical filters were removed at each station, and the material to be tested was glued over the inside of the port next to the animal's skin. These materials were herringbone twill cotton, serge, and sateen, with and without undershirt material. In this way, the efficacy of these fabrics in preventing skin burns could be assessed and compared with the results from Project 6.2 and with the laboratory studies reported in Annex 2.2, Part IX, Sec. 1.

2.8 DISTRIBUTION OF ANIMALS AND INSTRUMENTS

The proposed and final arrangements of animals and instruments at each station for exposure are given in Tables 2.3, 2.4, and 2.5.

TABLE 2.3 THE PROPOSED ARRANGEMENT OF EXPOSURE AT THE VARIOUS STATIONS FOR SHOT EASY

STATION	SLOW STRIP SHUTTER	OPEN PORT, QUICK SHUTTER	OPEN PORT, 3 FILTERS	OPEN PORT, 3 FABRICS	INSTRUMENTS
75	3 pigs 1 dog	3 pigs 1 dog	2 pigs 1 dog	. . . . .	1
76	3 pigs 1 dog	3 pigs 1 dog	2 pigs 1 dog	. . . .	1
77	3 pigs 1 dog	3 pigs 1 dog	2 pigs 1 dog	. . . .	1
78	2 pigs 2 dogs	. . . . .	3 pigs 2 dogs	2 pigs	1
78a	2 pigs	1 pig	2 pigs	2 pigs	1
79	2 pigs 2 dogs	. . . . .	3 pigs 2 dogs	2 pigs	1
TOTAL ANIMALS	22	13	21	6	6

TABLE 2.4 THE FINAL ARRANGEMENT OF EXPOSURE AT THE VARIOUS STATIONS FOR SHOT EASY

STATION	SLOW STRIP SHUTTER			OPEN PORT, QUICK SHUTTER		OPEN PORT, 3 FILTERS			OPEN PORT, 3 FABRICS	INSTRUMENTS
	Pigs		Dogs	Pigs, White	Dogs	Pigs,		Dogs	Pigs, White	
	White	Dark				White	Dark			
75	1	2	1	2	1	1	2	1	..	1
76	2	1	1	2	1	2	1	1	..	1
77	2	1	1	2	1	2	1	1	..	1
78	2	..	1	2	1	2	..	1	2	1
78a	2	..	..	1	..	2	..	..	2	1
79	2	..	1	2	1	2	..	1	2	1
TOTAL	11	4	5	11	5	11	4	5	6	6

TABLE 2.5 THE ARRANGEMENT OF EXPOSURE AT THE VARIOUS STATIONS FOR SHOT GEORGE

Proposed

STATION	SLOW STRIP SHUTTER	OPEN PORT, QUICK SHUTTER	OPEN PORT, 3 FILTERS	OPEN PORT, 3 FABRICS	INSTRUMENTS
75	3 pigs 1 dog	3 pigs 1 dog	2 pigs 1 dog	. . . . .	1
76	3 pigs 1 dog	3 pigs 1 dog	2 pigs 1 dog	. . . . .	1
77a	2 pigs 1 dog	1 pig 1 dog	1 pig 1 dog	. . . . .	1
77b	2 pigs 1 dog	1 pig 1 dog	1 pig 1 dog	. . . . .	1
78	2 pigs 2 dogs	. . . . .	3 pigs 2 dogs	2 pigs	1
79	2 pigs 2 dogs	. . . . .	3 pigs 2 dogs	2 pigs	1
Final[a]					
75	2 pigs	4 pigs	2 pigs	2 pigs	2
76	2 pigs	4 pigs	2 pigs	2 pigs	2

[a] All pigs were Chester Whites.

2.9 EVALUATION OF BURNS

As soon as possible after exposure, animals were retrieved from the stations and returned to the laboratory at Site L. Additional anesthesia was administered if necessary. Careful gross evaluation of the lesions was made, identification was checked, and animals were photographed in color. Biopsies of skin lesions were then performed. Biopsy material was identified, fixed, and embedded in paraffin blocks, using available Auto-Technicon equipment. The tissues were then returned to the laboratory at Rochester, New York, for sectioning, mounting, and microscopic study. Following biopsy, the animals were returned to the runs, allowed to recover from anesthesia, and observed daily for healing of the local wounds. Repeated biopsies were performed as indicated.

Chapter 3

Results

3.1 EXPOSURE STATIONS AND EQUIPMENT

In a previous report [1] the thermal-burn exposure stations were described in detail and the control studies recorded. This section of the report gives the performance of the stations during the Greenhouse Tests.

The over-all performance of the thermal exposure equipment during test time was good. There were a few shortcomings which became obvious in the field, most of which affected only the installation or operation, but some of which detracted from the experimental results themselves.

3.1.1 Shelters

All shelters were constructed by the contractor as designed, and performed according to plan. There was no significant blast, weather, or thermal damage to any station. The transport and anchoring of the sandspit station (78a) proved to be practical, and there was no evidence of displacement of this station following the blast.

There was some leakage of rain into both Stations 75 (Easy) and 75 (George) around the aperture plates. This was probably due to the inclined walls of these stations. Leakage was not seen in any other station. In the two stations where leaks occurred, there was some wetting of electrical equipment, which functioned in spite of this.

Some difficulty was experienced with animal crowding because of the limited horizontal

[1] Greenhouse Report, Annex 2.2, Part IX, Sec. 4.

interval between adjacent animals. Also, the inside vertical dimension of $5\frac{1}{2}$ ft was found undesirable because it provided inadequate head room for those working in the station.

The stations were designed with the animals in pairs, one above the other. This "double-decking" reduced the length of the structure to little more than half that of a "single-decked" station. This was done to conserve space on the shot islands. Experience with this arrangement pointed out two undesirable features. With the double-decked system, increasing the vertical size of the animal container to accommodate a larger animal became impossible. There was also a question as to whether the port on the bottom received the same thermal-radiation dose as the port on the top because of dust cloud phenomena, collimation by the port, and reflection from the ground.

3.1.2 Aperture Plates

The aperture plates functioned very well, with practically no failure due to intrinsic causes. There were no cases of blast damage to the plate or to the quartz windows. In Station 75 for Shot Easy, which received the highest thermal dose of any station, the neoprene gasket material burned, producing some clouding of the windows. Some additional clouding of the windows by dust also occurred.

The aperture plate with fast shutter performed satisfactorily, and no failures were attributable to it. Some minor specific weaknesses appeared, but these did not affect the test results. The shutter transport and release mechanisms, being on the external sur-

face of the plate, were subject to interference by dust, moisture, corrosion, and mechanical violence. The inclusion of the whole time-delay feature in the shutter mechanism itself made effective shutter time dependent upon the friction in the parts, which might, in turn, be modified by such factors as dirt, corrosion, lubrication, temperature, and wear.

The 2.85-cm (1.125 in.) diameter holes on the aperture plate with fast shutter produced good burns, but it was felt that this size was close to the minimum consistent with biological validity because of edge effects.

Performance of the aperture plates with slow shutters was satisfactory, and no failures were directly attributable to them. Some small difficulties occurred—mainly in the laboratory, and none of them affected the test results. It was found that the brass rack to the aluminum guide was an inferior bearing combination and tended to seize with small amounts of corrosion. Producing a looser fit and adequate lubrication surmounted the difficulty before test time. The abrupt stop at the end of the shutter travel sheared off gear teeth in the motor in one or two cases in the laboratory, even though the motor had been turned off by the limit switch by this time.

A shortcoming which became apparent after Shot Easy is mentioned in a previous report.[2] This was the lack of adequate means of determining the position of the animal in relation to the shutter at the time of the explosion. A satisfactory expedient for Shot George was the drilling of four holes in each plate to provide points of reference for the burns.

With the exception of one ultraviolet cell which leaked, the aperture plates with filters performed as planned without failure. The task of assembling the filters in the laboratory, especially the ultraviolet cell, proved somewhat tedious, and could probably be simplified. The aperture plates with fabrics, and aperture plates for instruments performed without failure.

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[2] *Ibid.*

3.1.3 Animal Containers

All animal containers performed their function according to design, which was basically sound. A little difficulty was experienced in crowding a few of the longer animals into the containers, and it was felt that some arrangement for adjusting the springs would have been desirable.

3.1.4 Ventilating System

The ventilation system proved to be entirely satisfactory. There was no instance of failure of any part of the system, and no evidence of any animal death due to inadequate ventilation or cooling.

3.1.5 Control System

All control systems worked well with the following exceptions: the fast and slow shutters were not actuated in Station 75 for Shot Easy or in Station 75 for Shot George. In the former instance failure was due to a human error in preparing the station for the shot, and in the second case failure was due to a blue-box failure. The fan, ventilation valve, battery, charger, converter, and recorder portions of the control system apparatus worked well.

3.2 RESULTS OF PHYSICAL MEASUREMENTS

3.2.1 Repair, Preparation, and Placement of Calorimeters and Recorders

The calorimeters and their accessories were escorted from the Zone of the Interior to Site L in order to ensure as gentle handling in transit as possible. Upon arrival, the instruments were unpacked, inspected for damage, and repaired. Eleven of the twelve instruments taken were made fully operative.

While the preparation and repair of the calorimeters was proceeding, the Speedomax recorders were made ready for use. Shipping damage was repaired, minor alterations and

adjustments were made, and each recorder was checked against a portable precision potentiometer.

As a final check on the ability of the calorimeters to compensate for ambient temperature changes, one set of instruments was placed in each of two thermal stations, with a mechanical timer set to turn the power on at 0600 hr and off at 0800 hr. When the records were retrieved, it was found that all bridges were negatively unbalanced. This check was repeated with the bridge balance adjustment set to give the maximum possible positive imbalance with the X- and R-arm thermistors equal (*i.e.*, no-signal condition); the records revealed that, although the recorders had not been driven off-scale negatively, the bridge output was much lower than that expected for equal temperatures of the receiving and compensating spheres.

Calculations revealed that the front spheres were assuming a temperature of about 0.5°C lower than that of the rear spheres. The explanation advanced for this was that, while the rear sphere was entirely surrounded by the instrument walls (at a temperature of about 25°C), the front sphere was looking directly at the night sky which has a radiating temperature about that of dry ice. Thus the front sphere was radiating to the sky and assuming an equilibrium temperature somewhat below that of the instrument case.

To investigate this phenomenon further, a calorimeter was mounted in the laboratory so that it looked into an enclosure which was blackened on the inside and surrounded by melting ice on the outside. A fan was used to draw room air through the enclosure, thus entirely surrounding the instrument with air at normal ambient temperature. Since the front spheres looked directly at a cold surface, this was an approximation to pre-shot conditions in the field. Again, the front spheres were found to assume a temperature of about 0.5°C below that of the rear spheres.

Inasmuch as all shots were scheduled for predawn, when the night sky effect would obtain, it was necessary to modify the calorimeters so as to prevent the negative imbalance of the recorders. This was done by inserting a resistance of known value in series with the R-arm thermistor of each calorimeter bridge. Each such resistor was hand wound with 10-ohm/ft nichrome wire and measured on a portable Wheatstone bridge. When all the calorimeters had been so modified, they were again checked for their behavior in the field and were found to behave satisfactorily.

The calorimeters and recorders were placed in the thermal stations on E—5 day and G—5 day. In each station for Shot Easy, one calorimeter was placed behind the top port on the extreme left as seen from the shot tower. For Shot George, two recorders were placed in each station, one behind the top left port and the other behind the top right one.

Each recorder was placed on the floor below a calorimeter and its power leads were connected to the station control panel. The leads from the recorder's solenoid pen—used to give a zero time mark on the recorder chart—were connected directly across the driving motor on one of the slow shutters.

On E—1 day and G—1 day, following a prepared check-off list, the sensitivity settings, the balance potentiometer positions, and the Speedomax operation were checked. Before leaving each station, the check-off list for the entire station was gone over again to ensure that all apparatus was ready to be actuated by the —30 min time signal and the blue-box (photocell) pulse.

3.2.2 Reduction of Data and Results

The data from the charts were read and tabulated. Corrections were made for variation in the chart width due to temperature and humidity and for changes in the bridge battery. The resistance of the thermistor corresponding to each reading was obtained by disconnecting the thermistors from each bridge and substituting resistance boxes in their places. With the calorimeters set as they were for the shot, each corrected point was reproduced on a Speedomax recorder and the resistance values were tabulated.

In order to get the temperature of the receiving sphere corresponding to the resistance of the thermistor, the thermistor calibration curve was plotted over the range covered by the data, using the relation between temperature and resistance for a thermistor given by [3]

$$\frac{R}{R_0}=\exp B\left(\frac{1}{T}-\frac{1}{T_0}\right) \qquad (3.1)$$

or

$$\log \frac{R}{R_0}=B\left(\frac{1}{T}-\frac{1}{T_0}\right).$$

This is an approximate relation, but it holds to a high degree of accuracy over short temperature ranges.

The resistance of each thermistor was known accurately at 5° intervals in the range from 20 to 60°C. All data covered a range between 25 and 35°C. Therefore, the value of B was calculated for 25 and 30°C and again for 30 and 35°C. The average of these two values was taken as the value of B at 30°C. Using this value, the resistance of the thermistor was calculated for several temperatures between 25 and 30°C and plotted against temperature. From this curve, the temperatures corresponding to the various resistance values of the thermistor on the cooling sphere were found. The ambient temperature (temperature of the calorimeter housing) was extracted in a similar manner.

The next step was to subtract the initial temperature of the front sphere (before the shot) from all the subsequent temperatures giving $T-T_0$. The temperature rise of the calorimeter housing was obtained in the same way. The temperature difference between the sphere and the housing at any time was then the difference between the rise of the sphere above its initial temperature ($T-T_0$) and the rise of the calorimeter housing above its initial temperature. This was ΔT.

ΔT was next plotted on semilog paper as a function of time, and a smooth curve was drawn through the points. It was shown in a previous report [4] that if ΔT was 1° or less,

the cooling was very nearly exponential. Therefore, the curve below 1° should be a straight line on semilog paper. This was found to be the case.

It was also shown that the energy received by the sphere is related to the area under the cooling curve by

$$E=\sum_i \alpha_i \int_{t_i}^{t_{i+1}} \Delta T dt \qquad (3.2)$$

where

$$\alpha_i=\frac{C_p \log \dfrac{\Delta T_i}{\Delta T_{i+1}}}{\Delta t} \qquad (3.3)$$

and can be considered constant over the time interval Δt. α_i was computed from the ΔT_i taken from the cooling curve plotted on semilog paper. The α_i were then plotted against time and a smooth curve was drawn through the points. By extrapolating this curve to zero time, an α_i could be chosen by means of which the cooling curve might be extrapolated to zero time giving the initial temperature rise.

Two methods of obtaining the area under the cooling curve (ΔT vs t) were avaliable. One was to choose Δt small enough so that α might be considered constant over the interval, and to measure the area under the curve in this interval with a planimeter. The other method was to choose Δt small enough so that the area under the curve in this interval might be considered the product of Δt and the ΔT at the mid-point of this interval. This latter method took less time and involved less chance for computation error since each step could be tabulated. It was felt that by taking small enough intervals, Δt, the total area under the cooling curve could be approximated to a higher degree of accuracy than by the planimeter method. This was the method used.

After having chosen the intervals, the ΔT at the mid-point of each interval was picked from the cooling curve on semilog paper and multiplied by the width of the interval. Each such elementary area was then multiplied by

[3] Greenhouse Report, Annex 2.2, Part IX, Sec. 3, Chap. 3.
[4] Ibid.

the α at the mid-point of the interval taken from the curve of α as a function of time. This process continued until ΔT had the value of 1. The sum of these elements gave the energy lost by the sphere up to the time when its temperature was 1° above that of its surroundings. The energy lost subsequently was equal to the heat capacity of the sphere. The sum of these two gave the total energy lost by the sphere in cooling and was equal to the energy received by the sphere as a result of its exposure to radiation.

Table 3.1 gives the results of the measurements made with the calorimeters. Column 4 of this table presents the energy transmitted by the visible filter assembly at each station; column 5 gives the energy transmitted by the infrared filters; and column 6, the energy measured behind a 7/16-in. protective quartz window. There is no column for ultraviolet energy, inasmuch as no measurable ultraviolet radiation was received at any station.

Since the energy measured by the calorimeters passed through a thin quartz window which was not present in the animal aperture plates, the measured values have been corrected for reflection losses at the two surfaces of this window by assuming a reflection loss of 4 per cent at each surface. Therefore the measured values were made to correspond to the energy incident on the animals.

The last column of Table 3.1 gives the total energy values corrected for losses due to the 7/16-in. quartz windows in the aperture plates.

The column with the heading "Predicted Energy" was calculated, using the formula:

$$E = \frac{fy}{4\pi R^2} e^{-\lambda R} \tag{3.4}$$

where

E = total thermal energy at distance R
y = total energy of the bomb (cal)
f = fraction of total energy of bomb that is thermal energy
R = distance in denominator (cm) distance in exponent (km)
λ = an average attenuation coefficient such that $e^{-\lambda R} = T$ = transmission.

The values of transmission used were obtained from the Naval Research Laboratory (NRL) and are:

$T = 0.68$ at 5.12 km and $\lambda = 0.073$ km^{-1}
(Easy)

$T = 0.61$ at 4.36 km and $\lambda = 0.114$ km^{-1}
(George)

The fraction f of the total energy of the bomb was taken to be 0.15 on advice from NRL.

TABLE 3.1   PREDICTED AND MEASURED VALUES OF THERMAL ENERGY FOR THERMAL STATIONS AT SHOT EASY AND SHOT GEORGE

SHOT EASY

STATION	DISTANCE (yd)	PREDICTED ENERGY (cal/cm²)	MEASURED ENERGY (cal/cm²)			TOTAL CORR. FOR THICK QUARTZ
			Visible	Infrared	Total	
75	1,325	34 to 45	13.9±1.4	15.2±1.5	13.2±1.5	14.2±1.6
76	2,270	11 to 14	4.6±0.4	4.0±0.4	6.2±0.5	6.6±0.5
77	3,109	5.6 to 7.5	4.6±0.3	4.1±0.3	6.9±0.5	7.5±0.5
78	3,500	4.2 to 5.6	3.5±0.3	3.5±0.3	5.6±0.3	6.1±0.3
78a	4,508	2.3 to 3.1	2.2±0.1	2.0±0.1	3.6±0.3	3.8±0.3
79	5,664	1.3 to 1.7	1.3±0.1		2.3±0.1	2.4±0.1

SHOT GEORGE

STATION	DISTANCE (yd)	PREDICTED ENERGY (cal/cm²)	Visible	Infrared	Total	TOTAL CORR. FOR THICK QUARTZ
75 Port I	3,460	15 to 21	5.1±0.4	6.7±0.4	9.1±0.7	9.8±0.8
76 Port I	4,785	6.6 to 9.5	3.6±0.3	4.6±0.3		
76 Port II	4,785	6.6 to 9.5	3.7±0.4	4.6±0.3	6.3±0.6	6.8±0.7

The measurements of Table 3.1 are presented graphically in Figs. 3.1, 3.2, and 3.3. Figure 3.1 gives a comparison among the measured values of total energy, the predicted values, and the values that would be expected at each station from inverse-square considerations based on the result at Station 79 (Site P). The curve of predicted values was plotted from points calculated by Eq. 3.4, using an average atmospheric transmission of 0.93 per km. Two points were plotted at each station corresponding to 45 and 60 kt.

Errors will be discussed in Sec. 4.2.1 of this report.

3.3 OBSERVATIONS ON EXPERIMENTAL ANIMALS

3.3.1 Pre-test Observations

(a) *Location of Animal Stations.* The stations were originally located to cover a wide range of thermal intensities for both shots (Tables 2.1 and 2.2). After the stations were built, it was found from measurements and calculations from Shot Dog that the effective thermal yield was lower than originally expected, being about one-sixth rather than one-third of the energy released. It was also found that a higher atmospheric attenuation occurred. The anticipated thermal intensity at each station was recomputed on the basis of these observations (Table 3.2), and it was found that the remote stations would receive low intensities. However, the range covered by the stations was still adequate. All stations were used for Shot Easy, but, because of residual radioactivity from Shot Dog and the operational hazards involved, Stations 75 and 76 only were used for Shot George. Atmospheric conditions were satisfactory for Shot Easy but torrential rains occurred for 48 hr prior to Shot George. This resulted in the collection of raindrops on the outside of the quartz windows of the exposure apertures, and the wet pigs caused condensation of moisture on the inner quartz surfaces.

(b) *Skin preparation.* On the day before Shot Easy, the animals were clipped and their skin was prepared for exposure. Although skin preparation was carried out by the technique described, the results were not satisfactory for two reasons. First, the clippers were supplied with No. 10 heads for coarse work instead of the No. 40 heads for fine clipping, which had been requested. Second, the animals had a dermatitis which resulted in a dirty rough skin. Little could be done to improve this situation before Shot Easy. Before Shot George, however, the skin was washed after clipping, and barium sulphide was applied as a paste. This was not satisfactory for although it removed the hair, the skin was irritated, so that some animals had to be discarded.

(c) *Transportation of Animals to Stations.* It was originally proposed to anesthetize the

TABLE 3.2 LOCATION OF THERMAL STATIONS AND RECALCULATED THERMAL ENERGY

(Refer to Tables 2.1 and 2.2)

SHOT EASY (50 KT)

STATION	DISTANCE (yd)	TOTAL INTEGRATED[a] THERMAL ENERGY (cal/cm²)
75	1,325	36 to 39
76	2,270	10 to 13
77	3,109	5.3 to 6.9
78	3,500	3.8 to 5.2
78a	4,508	2.2 to 3.1
79	5,664	1.1 to 1.8

SHOT GEORGE (250 KT)		
75	3,460	21 to 27
76	4,785	9.5 to 14

[a] Calculated from formula

$$E = \frac{fy}{4\pi R^2} e^{-\lambda R}$$

where E = total integrated thermal energy
  f = fraction of total energy of bomb as thermal energy
  y = total energy of the bomb
  R = distance
  λ = atmospheric attenuation coefficient where
    $e^{-\lambda R}$ = transmission = 0.81 – 0.94.
Thermal yield, 15 per cent of total energy.

TABLE 3.3 WEIGHT STUDIES ON DANISH LANDRACE PIGS

	FOOD AND WATER DEPRIVATION FOR 24 HR				FOOD DEPRIVATION FOR 24 HR; WATER AD LIB			
Pig No.	Weight (kg) 5 Apr 51	Weight (kg) 6 Apr 51	Weight (kg) Loss	Per Cent Loss	Weight (kg) 9 Apr 51	Weight (kg) 10 Apr 51	Weight (kg) Loss	Per Cent Loss
386	35.5	29.0	6.5	18.4	33.5	30.5	3.0	9.0
419	30.8	27.5	3.3	10.7	31.0	28.0	3.0	9.7
420	26.5	23.5	3.0	11.3	26.5	23.8	2.7	10.5
422	43.5	40.0	3.5	8.1	47.5	42.5	5.0	10.5
432	28.5	24.5	4.0	14.0	30.0	27.3	2.7	9.0
436	23.5	20.8	2.7	11.5	24.0	21.8	2.2	9.2
438	24.8	21.8	3.0	12.1	25.0	22.3	2.7	10.8
439	32.0	28.5	3.5	10.9	33.0	29.5	3.5	10.6
440	25.3	22.5	2.8	11.1	28.0	24.5	3.5	12.5
441	33.0	29.5	3.5	10.6	35.0	30.3	4.7	13.4
	RANGE OF LOSS=8.1 to 18.4 per cent				RANGE OF LOSS=9.0 to 13.4 per cent			
	AVERAGE LOSS=11.9 per cent				AVERAGE LOSS=10.5 per cent			

animals on Site L before transportation to the stations. However, in order to save several hours of anesthesia, the animals were transported to the exposure sites before they were anesthetized. The insulated liners for transportation provided excellent temperature and ventilation control, so all animals reached the stations in good condition.

(d) *Anesthesia*. Animals were anesthetized with 75 mg of Dial per kilogram of body weight for pigs and 60 mg of Dial per kilogram of body weight for dogs given intraperitoneally as outlined in Sec. 2.2. In the first dry run six of ten pigs died during the 24 hr following induction. The dosage of anesthesia given was based on a weight obtained before the animal was fasted. Observations on ten animals (Table 3.3) showed that, under the climatic conditions in the field, 11.9 per cent of body weight was lost when food and water were withheld for 24 hr and 10.5 per cent when food alone was withheld. Consequently, on E—3 day and G—3 day food was removed from the animal cages and the weight for calculating anesthesia dosage was obtained 24 hr later. The animals were then allowed to eat and drink until the actual operation began.

The anesthesia induction time corresponded to that observed in the laboratory. Of the 47 pigs and 15 dogs used in Shot Easy, four pigs and no dogs were found dead when the stations were reopened (Table 3.4). All the

dogs were still under deep narcosis, and two died within 48 hr despite efforts at resuscitation. Of 22 Chester White pigs used in Shot George, there were six deaths from anesthesia. Inclement weather on G—2 day and G—1 day had caused poor living conditions for these animals. At the time of induction of anesthesia the animals were cold and shivering. Many of the surviving pigs responded to stimulation but remained quiet when left undisturbed. All the dead pigs had marked rigor mortis, showing that they had

TABLE 3.4 MORTALITY FROM DIAL ANESTHESIA

SHOT EASY

STATION	PIGS		DOGS	
	Died	Survived	Died	Survived
75	1	7	0	3
76	2	6	1	2
77	0	8	0	3
78	0	8	0	3
78a	1	6	0	0
79	0	8	1	2
Total	4	43	2	13
Mortality, %	8.5		13.3	

SHOT GEORGE

STATION	PIGS		DOGS	
75	1	10		
76	5	6		
Total	6	16		
Mortality, %	27.3			
Combined Mortality, %	14.5		13.3	

died at least several hours before. These animals were discarded. None of the surviving pigs died from the Dial anesthesia after return to Site L.

(e) *Recovery of Animals.* The return of animals to the Site L laboratory on Easy Day was uneventful except for a change in the order of recovery necessitated by high residual radiation levels at Stations 77, 78, 78a, and 79. The animals from the thermal stations were kept in liners on the beach at Site E longer than had been proposed. However, there were no ill effects noted because of this change.

On George Day the weather was considerably worse at the time of recovery of animals from the stations. Heavy winds caused high waves in the lagoon; hence, the animals were jostled about and drenched during transportation in their containers.

3.3.2 Test Observations

(a) *Character, Pathology, and Course of Burns.* The burns produced in the field corresponded closely to those observed in the laboratory. Consequently, the same grading system was used in evaluating the lesions.[5] In this system, burns were graded 4+ to 0. The 4+ burn was one showing superficial charring of the skin with underlying coagulation. The 3+ burn showed complete coagulation of the exposed surface without charring. The 2+ burn showed patchy or central coagulation with underlying erythema. The 1+ burn was one with erythema present 24 hr after exposure, and 0 response was used when no damage was visible at 24 hr. Burns of all grades were observed in Shot Easy, varying from 4+ at Station 75 (1,325 yd) to 0 response at Station 78a (4,508 yd). No burn of greater than 2+ severity was observed in Shot George. Except in Station 75, Shot Easy, where animals developed radiation sickness, the subsequent clinical course and microscopic appearance of the lesions were identical to those in burns of comparable severity produced from laboratory sources of radiant energy.

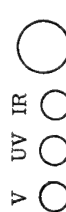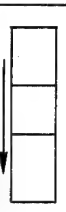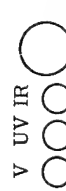[5] Greenhouse Report, Annex 2.2, Part IX, Sec. 1.
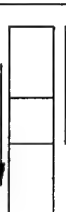
In Tables 3.5 to 3.12, pertinent data concerning the individual animals exposed at both Shot Easy and Shot George are presented. Each table represents one station. The position of the animal in the station corresponded to that shown in the table as viewed from the rear of the station. Animal number, type, color, type of aperture plate, resultant burn, reaction to anesthesia, and pertinent remarks are included.

In Table 3.13, the grades of burns occurring behind the unmodified ports, *i.e.*, covered only by fused quartz, are related to distance from bomb zero and amount of total integrated thermal energy calculated from formula in the pre-test period and from measurements recorded from the copper sphere radiometers at each station (Sec. 3.2.2). Animals which moved enough to receive burns in unclipped areas and those dying of Dial anesthesia were discarded before evaluation of data.

From Shot Easy 4+ burns were produced in all nine animals through the unmodified ports at Station 75 (1,325 yd) and in three dark animals at Station 76 (2,270 yd) and one dark animal at Station 77 (3,109 yd). The typical burn on the white pig in Station 75 had a central carbonized surface with a peripheral zone of white coagulation surrounded by a ring of intense erythema (Figs. 3.4a and b on page 71. The surface was dry and coagulated without edema, cyanosis, or weeping of serum. The dogs and dark-colored pigs had black charred burns. The surface of the lesion in the red or black pig was often broken with the epidermis destroyed or hanging in shaggy strands to expose the reddish-brown dermis beneath.

Figure 3.5 shows the microscopic appearance of a 4+ burn in a Chester White pig 13 hr after exposure at 1,325 yd. The epidermis was coagulated on either side and completely destroyed in the center. Nuclear pyknosis and slight change in staining were seen in the upper layer of the dermis, but the exact depth of the burn in the dermis was not apparent at this time. In all sections taken soon after burning, the level of demarcation

Table 3.5   DATA FOR SHOT EASY — STATION 75 (DISTANCE, 1,325 YD)

Position	1	3	5	7	9	11
Animal	Pig 272 (CW)	Pig 270 (CW)	Pig 267 (DL)	Pig 266 (DL)	Dog 981	
Color	White	White	Black	Black	Brown & white	
Shutter	Fast 22 msec	Fast 22 msec	Filter V UV IR	Filter V UV IR	Fast 22 msec	Radiometer
Burn	3+ 3+ 0	4+ 3+ 0	4+ 0 4+ 4+	4+ 0 4+ 4+	4+ 4+ 0	
Anesthesia	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	
Remarks	* Discard. Burn in unclipped area.	*	No UV burn	Second row of milder burns below. Pig moved	*	

Position	2	4	6	8	10	12
Animal	Pig 268 (DL)	Pig 269 (DL)	Pig 265 (CW)	Pig 271 (CW)	Dog 970	Dog 642
Color	Black	Black	White	White	Brown & white	Brown
Shutter	Slow strip	Slow strip	Slow strip	Filter V UV IR	Slow strip	Filter V UV IR
Burn	4+	4+	4+	- - - -	4+	4+ 0 4+ 4+
Anesthesia	Satisfactory	Satisfactory	Satisfactory	Died	Satisfactory	Satisfactory
Remarks	* Burn dry. Flame below	* Singed hair below area of burn	*	Pig dead at time of recovery. Discarded	*	

* Shutter did not move.

Table 3.6   DATA FOR SHOT EASY – STATION 76 (DISTANCE, 2,270 YD)

Position	1	3	5	7	9	11
Animal	Pig 204 (CW)	Pig 201 (CW)	Pig 205 (CW)	Pig 208 (DL)	Dog 935	
Color	White	White	White	Black	Black & white	
Shutter	Fast 22 msec	Fast 22 msec	Filter	Filter	Fast 22 msec	
Burn	3+ 0 2+	- - -	V UV IR 1+ 0 0 2+	V UV IR 0 0 3+ 4+	3+ 0 3+	Radiometer
Anesthesia	Satisfactory	Died	Satisfactory	Satisfactory	Satisfactory	
Remarks	2+ burn in unclipped area	Pig dead at time of recovery. Discarded	Burn in hair. Pig moved. Discarded for unmodified	Pig moved. Visible filter over unshaved area	Heavier burn over black spots	

Position	2	4	6	8	10	12
Animal	Pig 202 (CW)	Pig 207 (DL)	Pig 206 (CW)	Pig 203 (CW)	Dog 124	Dog 215
Color	White	Black	White	White	Black	Brown
Shutter	Slow strip	Slow strip	Slow strip	Filter	Slow strip	Filter
Burn	2+ 2+	4+ 4+	- - -	V UV IR 2+ 0 1+ 3+	4+ 3+	V UV IR 0 0 1+ 3+
Anesthesia	Satisfactory	Satisfactory	Died	Satisfactory	Satisfactory	Satisfactory
Remarks			Pig dead at time of recovery. Discarded	Pig moved. Unmodified burn in unclipped area		Anesthetic death at 48 hr

Table 3.7   DATA FOR SHOT EASY – STATION 77 (DISTANCE, 3,109 YD)

Position	1	3	5	7	9	11
Animal	Pig 253 (CW)	Pig 251 (CW)	Pig 225 (CW)	Pig 254 (CW)	Dog 886	
Color	White	White	White	White	White with black spots	
Shutter	Fast 22 msec	Fast 22 msec	Filter V UV IR	Filter V UV IR	Fast 22 msec	Radiometer
Burn	2+ 0 2+	1+ 0 2+	0 0 2+	0 0 1+	2+ 0 1+	
Anesthesia	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	
Remarks	Pig out of position. Burn in hair. Discarded	Pig out of position. Burn in hair. Discarded	No IR, V, or UV burn	No IR, V, or UV burn	Black spots singed; white less severe	

Position	2	4	6	8	10	12
Animal	Pig 224 (CW)	Pig 252 (CW)	Pig 256 (DL)	Pig 255 (DL)	Dog 742	Dog 932
Color	White	White	Black	Black & brown	Brown & white	Black spotted
Shutter	Slow strip	Slow strip	Slow strip	Filter V UV IR	Slow strip	Filter V UV IR
Burn	0 2+	0 2+ 1+ 2+	0 3+	1+ 0 0 3+	2+	2+ 0 1+ 4+
Anesthesia	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory
Remarks						Black spots carbonized. White mild

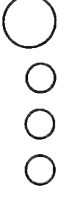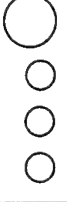Table 3.8 DATA FOR SHOT EASY — STATION 78 (DISTANCE, 3,500 YD)
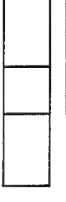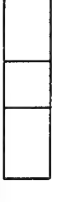
Position	1	3	5	7	9	11
Animal	Pig 263 (CW)	Pig 260 (CW)	Pig 257 (CW)	Pig 259 (CW)	Dog 961	
Color	White	White	White	White	Black & white	
Shutter	Fabric	Fabric	Filter V UV IR	Filter V UV IR	Fast 22 msec	Radiometer
Burn	None	0 0 0 1+	0 0 0 1+	0 0 0 1+	3+ 1+ / 0 0 1+	
Anesthesia	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	
Remarks				No burn visible after 48 hr	Scorching on black areas	

Position	2	4	6	8	10	12
Animal	Pig 258 (CW)	Pig 264 (CW)	Pig 261 (CW)	Dog 498	Pig 262 (CW)	Dog 785
Color	White	White	White	Brown & white	White	White with dark spots
Shutter	Slow strip	Slow strip	Fast 22 msec	Slow strip	Fast 22 msec	Filter V UV IR
Burn	1+	1+ 1+	0 0 1+	2+ 1+	0 0 0 0	1+ 0 0 2+
Anesthesia	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory
Remarks		Died. Nembutal anesthesia. 3 days	Died. Nembutal anesthesia. 3 days	Deeper burn on brown area		

Table 3.9 DATA FOR SHOT EASY – STATION 78a (DISTANCE, 4,508 YD)
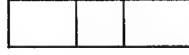
Position	1	3	5	7
Animal	Pig 218 (CW)	Pig 223 (CW)	Pig 221 (CW)	
Color	White	White	White	
Shutter	Filter V UV IR (circles)	Fabric (circles)	Fabric (circles)	Radiometer
Burn	None	None	None	
Anesthesia	Satisfactory	Satisfactory	Satisfactory	
Remarks				

Position	2	4	6	8
Animal	Pig 217 (CW)	Pig 222 (CW)	Pig 219 (CW)	Pig 220 (CW)
Color	White	White	White	White
Shutter	Slow strip	Fast 22 msec (circles)	Slow strip	Filter V UV IR (circles)
Burn	None	None	None	None
Anesthesia	Satisfactory	Died	Satisfactory	Satisfactory
Remarks		Anesthesia death		

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Table 3.10   DATA FOR SHOT EASY – STATION 79 (DISTANCE, 5,664 YD)
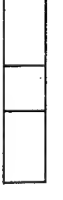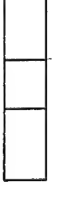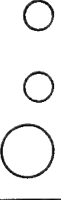
Position	1	3	5	7	9	11
Animal	Pig 212 (CW)	Pig 213 (CW)	Pig 210 (CW)	Pig 214 (CW)	Dog 940	
Color	White	White	White	White	Black & white	
Shutter	Fabric	Fabric	Filter V UV IR	Filter V UV IR	Fast 22 msec	Radiometer
Burn	None	None	None	None	Died	
Anesthesia	Satisfactory	Satisfactory	Satisfactory	Satisfactory		
Remarks					Died 48 hr after induction	

Position	2	4	6	8	10	12
Animal	Pig 211 (CW)	Pig 216 (CW)	Pig 209 (CW)	Dog 225	Pig 215 (CW)	Dog 941
Color	White	White	White	Black & white	White	Black & white
Shutter	Slow strip	Slow strip	Fast 22 msec	Slow strip	Fast 22 msec	Filter V UV IR
Burn	None	None	None	None	None	None
Anesthesia	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory
Remarks						

Table 3.11   DATA FOR SHOT GEORGE – STATION 75 (DISTANCE, 3,460 YD)

Position	1	3	5	7	9	11
Animal		Pig 336 (CW)	Pig 334 (CW)	Pig 212 (CW)	Pig 213 (CW)	
Color		White	White	White	White	
Aperture plate	Radiometer	Fast• 450 msec	Fast 300 msec	Fast 150 msec	Fast 30 msec	Radiometer
Burn		2+ 2+ 0	1+ 0 0	1+ 0 0	2+ 0 0	
Anesthesia		Satisfactory	Satisfactory	Satisfactory	Satisfactory	
Remarks		*	*	*	*	

Position	2	4	6	8	10	12
Animal	Pig 214 (CW)	Pig 335 (CW)	Pig 347 (CW)	Pig 333 (CW)	Pig 341 (CW)	Pig 215 (CW)
Color	White	White	White	White	White	White
Aperture plate	Filter V UV IR	Fabric	Slow strip	Slow strip	Fabric	Filter V UV IR
Burn	0 0 0 / 0	0 0 2+ / 0 0 0	1+	2+	– – –	0 0 0 / 0 0 2+
Anesthesia	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Died	Satisfactory
Remarks		No burn under fabrics	*	*	Died of anesthesia. Discarded	

* Shutter did not move.

Table 3.12   DATA FROM SHOT GEORGE – STATION 76 (DISTANCE, 4,785 YD)
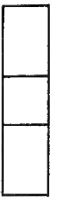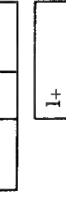
Position	1	3	5	7	9	11
Animal		Pig 342 (CW)	Pig 330 (CW)	Pig 344 (CW)	Pig 343 (CW)	Pig 350 (CW)
Color		White	White	White	White	White
Aperture plate	Radiometer	Fabric	Fabric	Fabric Fast 150 msec	Fast 300 msec	Filter V UV IR
Burn		- - -	1+ 0 0 1+	- - -	1+ 0 0	- - -
Anesthesia		Died	Satisfactory	Died	Satisfactory	Died
Remarks		Died of anesthesia. Discarded	Slight burn behind sateen	Died of anesthesia. Discarded		Died of anesthesia. Discarded

Position	2	4	6	8	10	12
Animal	Pig 329 (CW)	Pig 346 (CW)	Pig 345 (CW)	Pig 337 (CW)	Pig 338 (CW)	Pig 350 (CW)
Color	White	White	White	White	White	White
Aperture plate	Filter V UV IR	Slow strip	Slow strip 1+	Fast 30 msec	Fast 450 msec	Filter V UV IR
Burn	0 0 0 0	- - -		1+ 0 1+	- - -	- - -
Anesthesia	Satisfactory	Died	Satisfactory	Satisfactory	Died	Died
Remarks		Died of anesthesia. Discarded			Died of anesthesia. Discarded	Died of anesthesia. Discarded

TABLE 3.13 BURNS AS A FUNCTION OF DISTANCE AND ENERGY

SHOT EASY

STATION	DISTANCE FROM BOMB ZERO (yd)	TOTAL INTEGRATED THERMAL ENERGY (cal/cm²)		ANIMALS OBSERVED	BURNS BEHIND UNMODIFIED PORTS				
		Calculated	Observed		4+	3+	2+	1+	0
75	1,325	36 to 39	13.2±1.5	6 pigs	6				
				3 dogs	3				
76	2,270	10 to 13	6.2±0.5	4 pigs	2	1	1		
				3 dogs	1	2			
77	3,109	5.3 to 6.9	6.9±0.5	6 pigs		2	3	1	
				3 dogs	1		2		
78	3,500	3.8 to 5.2	5.6±0.3	8 pigs				6	2
				3 dogs		1	2		
78a	4,508	2.2 to 3.1	3.6±0.3	6 pigs					6
				0 dogs					
79	5,664	1.1 to 1.8	2.3±0.1	8 pigs					8
				2 dogs					2
SHOT GEORGE									
75	3,460	21 to 27	9.1±0.7	9 pigs			5	3	1
76	4,785	9.5 to 14	6.3±0.6	5 pigs				4	1

in depth was not obvious. Demarcation is well seen in Fig. 3.6, which is a section of pig skin 74 hr after exposure at 1,325 yd. The injured dermis then had a basophilic staining reaction, the blue color of which contrasted sharply with the red eosinophilic staining of the viable tissue. There was an inflammatory zone of leukocytic infiltration at the base of the dead tissue which separated it from the living dermis. Healing by proliferation of epithelium from the uninjured hair follicles was beginning.

The method of repair is seen in Fig. 3.7, which shows a section of pig skin taken 122 hr (5 days) after exposure at 1,325 yd. In this illustration, the epithelium is shown growing from the viable epidermis of the hair follicle and proliferating in a sheet beneath the eschar formed by the devitalized tissue. This proliferative response of the epithelium proceeded from all viable hair follicles, with eventual meeting and blending of the individual sheets to form a new epidermis. Seen in section, this process began as a heaping up of epidermis at either side of the hair follicle followed by peripheral extension of a thin projection of epithelium often only one or two

cells thick. As this process proceeded away from the parent follicle, proximally it became thicker and took on the appearance of epidermis with new papillae while the leading edge remained thin. Figure 3.8 shows the healing observed in a pig at 228 hr (9½ days) after exposure at 1,325 yd. It is seen that the burned tissue was separated from the surface of the epidermis and covered it only as an eschar. Careful inspection along the space between epidermis and eschar showed attachment by hairs and occasional small areas of delayed healing. At this stage, the eschar which formerly covered the whole burn began to loosen and curl up at the edges. Its gross appearance was leathery. Beneath the curled edges was a delicate epithelium which was depigmented in the dark animals (Fig. 3.9). The eschar could be easily removed if the surface beneath was completely healed, but was firmly attached to unhealed areas. In one animal, the eschar was deliberately pulled off an unhealed granulating bed. Another eschar promptly formed and healing, although delayed, occurred uneventfully.

From Shot Easy 3+ burns were produced in three animals at Station 76 (2,270 yd), two

dark animals at Station 77 (3,109 yd), and one dark animal at Station 78 (3,500 yd). These burns revealed uniform surface coagulation with a narrow surrounding zone of erythema. Grossly, the only difference from the 4+ burns was the absence of carbonization of the superficial epidermis. Figures 3.10a and b (page 71) show the gross appearance of a 3+ burn at 11 and 74 hr, respectively. The subsequent course of healing was similar in the 3+ and 4+ lesions.

The microscopic appearance of the burn in a black pig 15 hr after exposure to 50 kt at 3,109 yd in Station 77 is shown in Fig. 3.11. This illustrates the appearance of the transepidermal necrosis from a 3+ burn seen soon after the injury, at which time demarcation in depth was not apparent. It also shows the abrupt lateral border between damaged and normal epidermis. In 74 hr, the depth of injury was obvious as shown in Fig. 3.12, where the blue basophilic staining of the damaged tissue above contrasts with the eosinophilic stain of the normal dermis below. The uniformity of the depth of injury shown was characteristic of this burn.

From Shot Easy 2+ burns were produced in one animal at Station 76 (2,270 yd), five animals at Station 77 (3,109 yd), and two animals at Station 78 (3,500 yd). From Shot George five of the nine white pigs at Station 75 (3,460 yd) incurred similar burns. A 2+ burn behind a slow-shutter port of Station 76 at 2,270 yd is shown in Figs. 3.13a and b on page 73. At 11 hr, there was a pink hyperemic area with central white coagulation, but at 124 hr the burn became uniformly darker with a reddish-brown hue. The surface of these burns was always dry without edema or weeping of serum. Healing with separation of the eschar occurred more rapidly than in the 3+ burns.

The microscopic appearance of a 2+ burn in a Chester White pig 15 hr after exposure is shown in Fig. 3.14. It is seen on the left that transepidermal injury was present with complete destruction of epidermis but without a definite line of demarcation in the dermis.

The abrupt juncture between injured and uninjured epidermis is shown in the center. Complete re-epithelialization of these burns occurred rapidly as shown in Fig. 3.15, a photomicrograph of a section of the same burn at 123 hr.

From Shot Easy 1+ burns were produced in one white pig at Sation 77 (3,109 yd) and six white pigs at Station 78 (3,500 yd). From Shot George similar burns were produced in three white pigs at Station 75 (3,460 yd) and four white pigs at Station 76 (4,785 yd). The gross appearance of a 1+ burn through a slow-shutter aperture at 17 hr in a Chester White pig is shown in Fig. 3.16a on page 73, where the typical persistent erythematous lesion without surface coagulation is seen. By 72 hr these lesions began to change in color to a brownish mottling area on a background of normal-appearing epidermis as shown in Fig. 3.16b, on page 73. Subsequently, desquamation of the discolored epidermis occurred, leaving an apparently uninjured skin surface.

The histological appearance of a 1+ burn at 11 hr on a Chester White pig at Station 76, Shot George (4,785 yd) is illustrated in Fig. 3.17 which shows injury of the superficial layer of the epidermis with only scattered areas of damage to the basal layer and papillae.

From Shot Easy no burns could be discerned in two white pigs at Station 78 (3,500 yd), six white pigs at Station 78a (4,508 yd), and eight white pigs and two dogs at Station 79 (5,664 yd). From Shot George one white pig in Station 75 (3,460 yd) and one in Station 76 (4,785 yd) were not burned. These animals were observed at the time of recovery and subsequently for several days without finding evidence of injury.

(b) *Species Differences in Response to Thermal Energy.* Grossly, dogs sustained more severe burns than did the pigs exposed at the same stations. In 4+ and 3+ burns the skin of the dogs showed greater contracture and depression of the surface in the early stages. In 48 to 72 hr there was surrounding edema and the central burned area cracked and began to ooze serum and pus. Sloughing

of the area occurred early leaving a dirty granulating surface which healed by contracture and marginal epithelialization. The less severe burns in the dogs were not striking in the early phases although some edema was present. In 24 to 48 hr there was increased swelling and serum began to weep from the wound. Some of these lesions sloughed. The healing time was longer in the dog than in the pig. At Station 77, Shot Easy, average healing time of the burns on white pigs was 8 days; of those on black pigs, 16 days; of those on dogs, 19 days. At Station 78, Shot Easy, where only mild burns were sustained in all animals, those on the pigs had disappeared in 5 to 7 days while those on the dogs required an average of 18 days to heal. Microscopically, the depth of injury was more difficult to assess in the dog than in the pig as shown in Fig. 3.18a on page 58 taken at 12 hr and in Fig. 3.18b (page 59) at 124 hr from a dog in Station 75, Shot Easy (1,325 yd).

(c) *Effect of Animal Color on Burns Produced*. At the same stations, dark-colored animals received more severe burns than did white ones (Table 3.14). The two 4+ burns found in Station 76, Shot Easy, were in black pigs. The two white pigs in this station received 3+ and 2+ burns, respectively. In Station 77, Shot Easy, 3+ burns were produced in two black pigs, whereas four white pigs showed one 1+ and three 2+ burns. Figures 3.19a and 3.19b (pages 60 and 61) show microscopically the greater depth of burn in a black pig from Station 76, Shot Easy, as compared to a white pig from the same station. Healing with depigmentation of the skin was the end result of a deep burn in a dark-skinned animal as shown in Fig. 3.9. Spotted dogs in Stations 76, 77, and 78, Shot Easy, showed more severe burns in the darker colored area. Figure 3.20 shows a photograph of one such animal; the dark areas later broke down and showed slower healing than the white skin.

(d) *Burns Produced behind Filter Apertures*. Animals were exposed behind filter aperture plates which transmitted the unmodified radiant energy and that in the ultraviolet, visible, and near infrared portions of the spectrum, respectively (cf. Sec. 2.6 and Annex 2.2, Part IX, Sec. 3).

Through the port which admitted only the ultraviolet light, there were no burns produced in any of the animals at any station. Although these animals were observed carefully to determine if any delayed reaction occurred from the photochemical effects of ultraviolet light, no changes were noted.

The burns produced behind the visible filters were of the same degree as those produced behind the infrared filters in seven animals. In four animals slightly more severe burns were sustained behind the visible than behind the infrared filters.

The burns through the unmodified openings in the filter plates were always more severe than those through limiting filters at the same station. The clinical behavior of the lesions produced behind visible and infrared filters was identical to that of unmodified burns of similar severity.

(e) *Burns Produced as a Function of Time*. On Shot Easy, the fast shutters were set to shift at 20 to 25 msec, as recorded in Sec. 2.5(a) and in Annex 2.2., Part IX, Sec. 4. Mechanically, the shutters functioned well except at Station 75, where they failed to trip. In every instance where the shutters worked, no burn was sustained behind the aperture which was open during the first 20 to 25 msec. Burns sustained through the ports which were open after 20 to 25 msec were in most cases equal in severity to those through the unmodified ports. Satisfactory exposures through these apertures were obtained in seven animals: one in Station 76, one in Sta-

TABLE 3.14 BURNS PRODUCED IN WHITE AND DARK-COLORED PIGS

STATION	WHITE PIGS					DARK PIGS				
	4+	3+	2+	1+	0	4+	3+	2+	1+	0
75	2					4				
76		1	1			2				
77			3	1			2			
78				6	2					
78a					6					
79					8					

tion 77, three in Station 78, and two in Station 79.

The slow strip shutters for Shot Easy, described in Sec. 2.5(b) and in Annex 2.2, Part IX, Sec. 4, functioned in all stations except Station 75, where they did not move. Each shutter was arranged so that the 5-in. opening shifted 3 in. in 2 sec in a cephalad direction. Fourteen satisfactory exposures were obtained: three at Station 76, four at Station 77, three at Station 78, one at Station 78a, and three at Station 79. There were no burns produced at the latter two stations, so no data for evaluation of burning time were obtained. In the ten remaining animals, the burns produced appeared uniform over the caudal 5-in. length of burn which was that part exposed initially. Some of the burns showed an additional $\frac{3}{8}$ to $\frac{1}{2}$ in. of less severe damage at the cephalic end of the burned strip. This was in the remaining 3 in. which was exposed by the opening shutter. Figure 3.16a shows a uniform erythematous lesion without surface coagulation produced behind a sliding shutter. Yet in Fig. 3.16b, which shows the appearance of this burn at 74 hr, deeper injury is seen in the 2 in. on the left, where the shutter was open throughout the exposure. The figure shows that the burn to the right of the totally exposed area appears to diminish in intensity toward the right which was the area covered by the sliding shutter as it moved from right to left.

Since burning occurred behind the opening portion of the shutter for a maximum distance of $\frac{1}{2}$ in. and since the shutter traveled 3 in. in 2 sec, it was presumed that the burn was sustained in the first $\frac{1}{3}$ sec after the explosion. Changes were made in both fast and slow shutters for Shot George in order to study this time interval more critically.

For Shot George a series of microswitches were designed to flip four fast shutters at 30, 150, 300, and 450 msec, respectively (Sec. 3.1). In order to provide definite points of reference for locating the burn behind the slow shutter, holes were bored through the exposure plate, two holes beneath the ends of the shutter aperture in its starting position and two in its final position. Small round burns through these holes would provide an index of shutter position on the strip burn. Two of the modified slow strip shutters and one set of the four fast shutters were used in each of the stations for Shot George.

Due to a failure in the photoelectric relay, none of the shutters functioned in Station 75. In Station 76 the pigs behind the fast shutters tripping at 150 and 450 msec died of anesthesia. In the 30-msec exposure there was no burn, and the burn occurring after this time was equal in severity to the unmodified burn. Before or after 300 msec no burn was observed, whereas a 1+ burn was present behind the unmodified aperture in this animal. One of the two animals behind the slow shutters died of anesthesia. The remaining animal showed a 1+ burn in the caudal part of the strip, a more severe 1+ burn in the central part, and no burn in the cephalic portion.

(f) *Protective Effects of Fabrics.* In the experiment designed to test the protective effects of herringbone twill, sateen, and serge, with and without underwear, exposures were made on two animals each at Stations 78, 78a, and 79, Shot Easy. No burns occurred behind the unmodified ports or behind any fabrics at Stations 78a and 79. In Station 78, a 1+ burn was produced behind the unmodified port on one animal and no burn was produced on the other. No burns occurred behind the fabrics on either animal. In Shot George fabrics were again tested on two animals in each station. One animal at each station died of anesthesia. At Station 75, a 2+ burn occurred on the remaining animal behind the unmodified port, but no burn was produced behind the fabrics. At Station 76, where a 1+ burn was found behind the unmodified port, a 1+ burn was also found behind the sateen. At this station no burn occurred behind herringbone twill or serge.

(g) *Effects of Ionizing Radiation on Thermal Burns.* The ten animals which recovered from Dial anesthesia in Station 75, 1,325 yd

from a 50-kt shot, received sufficient ionizing radiation to cause death in all but one. The latter pig became blind and spastic, apparently from a cerebral hemorrhage during the radiation sickness. Some of the clinical data on these animals are given in Table 3.15. It was noted that all of the six pigs which died and one of the three dogs had no sign of interference with the healing of their wounds in spite of fatal radiation sickness. After healing was completed, sections demonstrated that the epidermis was atrophic in appearance as shown in Fig. 3.21.

In two dogs, the burns were covered with healthy granulations up to 2 days before death. At this time, the wounds became gangrenous. This change was shown in a dog at 124 hr in Fig. 3.22a (on page 75) and at 235 hr in Fig. 3.22b. At the time of the first picture, the wound was clean, but it later became gangrenous. The dog died of radiation sickness a few hours after the second photo-graph was made. In one pig, this terminal gangrene also occurred in the biopsy wound, which was open and unhealed at the time of death 10 days after operation. The terminal breakdown of the two unhealed burns and the biopsy wound in these animals contrasted strikingly with the uninterrupted healing seen in the others.

Death occurred in two of these pigs on the 12th day from light nembutal anesthesia given to obtain photographs and biopsies at a time when they were seriously ill. In one of them, a large hematoma developed in a venipuncture site.

There were post-mortem findings in all animals of an intense, fibrino-hemorrhagic peritonitis across the abdominal cavity directly behind the exposure apertures. This was more marked than in animals from other experiments, which had a general distribution of whole-body radiation rather than a concentrated beam in one area.

TABLE 3.15   OBSERVATIONS ON ANIMALS AT STATION 75—SHOT EASY

ANIMAL	DIARRHEA, 3 DAYS	WBC, 6 DAYS	WBC, 12 DAYS	DEATH	CONDITION OF WOUND
Pig 272	+	4,300	3,700	12 days	Healed
Pig 268	+	2,100	2,100	15 days	Healed
Pig 270	+	5,650		11 days	Healing well
Pig 269	+	2,550	240	12 days (anesthesia)	Healed
Pig 267	+	6,800	4,900	12 days (anesthesia)	Healed
Pig 265	+	2,100		10 days	Burn healing. Gangrene, biopsy wound
Pig 266	+	5,700	3,500	Survived, blind & spastic	Healed
Dog 981	+			14 days	Terminal gangrene
Dog 970	+			14 days	Clean granulations
Dog 642	+	175		10 days	Gangrene

Chapter 4

Discussion

4.1 EXPOSURE STATIONS

The Greenhouse field test permitted little equipment modification on the basis of performance. Therefore, as many difficulties as possible had to be foreseen. It was inevitable that additional shortcomings would become evident during the test period, and the principal ones have been mentioned in Chap. 3. In the event of future tests utilizing similar apparatus, most of the equipment used in Operation Greenhouse could be improved by certain revisions. These are covered under separate headings.

4.1.1 Shelters

The shelters should be increased in height to provide head room, and in length to leave more room between adjacent animals. All animals should be placed on the same level. Gasketing between the aperture plate and steel frame would help prevent leakage of rain into the station. Suitable drainage around the station would assist in keeping the inside of the station dry.

4.1.2 Aperture Plates

Some of the smaller apertures should be increased in size, even if this requires reducing the number of apertures. A means should be devised to protect the windows from dust just prior to the shot. This could be in the form of a large shutter covering the entire port which could be released automatically. Shielding the neoprene with aluminum foil would prevent its burning in the closer stations.

A fast-acting, enclosed, rotary or linear solenoid would circumvent many of the weak points of the fast shutter mechanism. It would be better protected from mechanical damage and entry of water or dust. The shutter action could be made more rapid and the time delay introduced externally into the electrical circuit.

If the slow shutter were to be used again, it should have some means of indexing, *i.e.*, indicating where the animal was in relation to the shutter at the time of burn. This could be done in several ways. Better materials should be used in the moving members from the standpoint of bearing surfaces. Another improvement would be to have switches at each end of the travel, in conjunction with reversing control on the main panel. This would permit all shutters to be repositioned remotely at one time, thus simplifying the equipment. The incorporation of a friction clutch in the motor pinion would prevent undue strain on the gear train during the rapid deceleration at the end of shutter travel.

Future ultraviolet filters should have improved liquid cells, which would be easier to assemble and less likely to leak, and which could be filled several days prior to use. Since the Greenhouse Tests indicated that no burns were produced behind the ultraviolet filters, it is doubtful whether they would be used again.

4.1.3 Animal Containers

Although satisfactory operation was obtained from the animal containers, it would

be desirable to have them a few inches longer for the size of animal that was used. Adjustable springs would facilitate the proper approximation of animal to aperture plate.

4.1.4 Ventilation System

The design of this system proved basically sound, and probably little modification would be undertaken for any future tests. With single-decked animals, however, duct work could be much less complicated. One main horizontal trunk with suitably placed holes would direct a stream of air down on top of each animal, and be considerably simpler than the double-deck style.

4.1.5 Control System

Efforts in improving the control system should be directed primarily toward simplification. This would reduce the number of components which could fail, and lessen the chance of human error. Although no difficulty was experienced with moisture or corrosion of this equipment, it was felt that the exposed type of construction was too vulnerable in this respect. Watertight type of construction should be used in the future, and connections made by AN or similar connectors.

In order to decrease the probability of bluebox failure, the unit should be placed inside the station, where it would be protected from the rain. Multiple units could be used to produce greater reliability.

4.2 DISCUSSION OF PHYSICAL MEASUREMENTS

4.2.1 Uncertainties in the Measurements

In order to determine the magnitude of the uncertainty in any temperature measurement, the Wheatstone bridge circuit was solved for the resistance of the thermistor in the receiving sphere giving

$$X = \frac{Rk_5 - \dfrac{E_L}{E}(Rk_2 + k_1)}{k_6 + \dfrac{E_L}{E}(Rk_4 + k_3)}. \tag{4.1}$$

Here X is the resistance of the thermistor in the receiving arm of the bridge, R is the resistance of the thermistor in the reference arm of the bridge. E_L is the emf across the bridge load, and E is the emf of the dry cell driving the bridge. The constants k_1 through k_6 contain the circuit constants.

The relation between the thermistor resistance and the temperature is given by

$$X = X_0 \exp B\left(\frac{1}{T} - \frac{1}{T_0}\right) \tag{4.2}$$

where X is the resistance of the thermistor at temperature T ($^\circ$K), X_0 is the resistance of the thermistor at temperature T_0 ($^\circ$K), and B is a constant which depends on a particular thermistor.

Equating Eqs. 4.1 and 4.2, taking the logarithm, and solving for T there results

$$T = \frac{BT_0}{B + T_0 \log \dfrac{Rk_5 - E_L/E(Rk_5 + k_1)}{k_6 + E_L/E(Rk_4 + k_3)}} \tag{4.3}$$

or

$$T = T(T_0, R, E_L, E, B). \tag{4.4}$$

The maximum uncertainty in a temperature measurement can be calculated by taking the total differential of T:

$$dT = \frac{\partial T}{\partial T_0}dT_0 + \frac{\partial T}{\partial R}dR + \frac{\partial T}{\partial E_L}dE_L + \tag{4.5}$$
$$\frac{\partial T}{\partial E}dE + \frac{\partial T}{\partial B}dB.$$

The uncertainties in E_L and E were random since they resulted from the inherent differences in the Speedomax recorder and random human errors due to reading. Therefore, the determination of the maximum possible error in a temperature difference calculated from two readings from the recorder required that the uncertainties due to E_L and E be added together. On the other hand, the uncertainties due to T_0, R, and B tended to cancel in calculating temperature difference, since these were not random errors with respect to measurement.

Figure 4.1 gives the maximum uncertainty in the temperature differences represented by

the unbalanced voltage recorded by the Speed-omax for the various sensitivities used. These curves were calculated using Eq. 4.5 after performing the indicated operations and taking into account the fact that the random errors due to E_L and E added and the non-random errors due to T_0, R, and B tended to cancel out. The errors given in Table 3.1 were computed from the curve in Fig. 4.1 and represented the uncertainty in the measurements, assuming the validity of the extrapolation of the cooling curve to zero time.

The preparation for the Greenhouse experiment was done with the expectation that higher energies would be found in the field than were encountered. As a result, calorimeters were exposed at these expected levels and it was found that, with the resulting cooling curves, the error in extrapolation to zero time was less than 2 per cent. The standard exposure time was 1 sec, but longer exposure times did not increase the error appreciably at these energy levels.

At lower levels, one would expect that the relative effect of the error made in extrapolating the cooling curve to zero time would become greater and would depend on the time of exposure to a greater degree. This effect would cause the values calculated from the area under the cooling curve extrapolated to zero time to appear greater than they actually were. Inasmuch as the method of recording the temperatures of the sphere necessitates extrapolation, this source of uncertainty is present in the results given in this report.

In an attempt to determine the magnitude of this effect, it was found that the curve for α as a function of time could be represented to a high degree of accuracy by the equation

$$\alpha(t) = \alpha_\infty + \beta e^{-kt} \qquad (4.6)$$

where $\alpha(t)/C_p$ is the slope of the log cooling curve, β and k are constants which can be determined for any set of data, and α_∞ is the asymptotic value for $\alpha(t)$. Therefore, the slope of the log cooling curve is given by

$$\frac{d(\log \Delta T)}{dt} = \frac{\alpha_\infty}{C_p} + \frac{\beta}{C_p} e^{-kt} \qquad (4.7)$$

which on integration gives

$$\log \frac{\Delta T}{\Delta T_0} = \frac{\beta}{kC_p}(1 - e^{-kt}) - \frac{\alpha_\infty}{C_p}. \qquad (4.8)$$

ΔT_0 can be calculated from this equation. That this equation describes the cooling curve to well within the accuracy of the measurements is shown by the fact that any point of the curve beyond about 15 sec after exposure can be used to calculate ΔT_0 and gives the same result as any other point.

Therefore, the cooling curves, from which the results given in Table 3.1 were calculated, were consistent with Eq. 4.8 to within about 15 sec of zero time. Furthermore, it was shown in Annex 2.2, Part IX, Sec. 3, Chap. 3, that for 1-sec exposure, the sphere began cooling with uniform surface temperature in the range from 10 to 12 sec. Longer exposure time tended to increase the time required to establish this isothermal condition. The conclusion was that the time of appearance of the isothermal condition was not appreciably longer than for 1-sec exposures, and therefore the magnitude of the error due to the longer exposure time was not appreciably increased. The relative error, however, was increased at the lower energy levels.

Because of the lack of detailed information on the first 15 sec of the cooling curves, a firm estimate of this uncertainty was not possible. However, it could be stated that the values given in Table 3.1 represent an upper limit of the energy incident on each station. A lower limit could be determined on the assumption that the temperature difference of the sphere at 15 sec was proportional to the energy of the sphere at that time. The total energy which was collected by the sphere was between these two limits. The ranges given in Table 3.1 are in the region between these limits.

4.2.2 Discussion of Results

Transmission curves for the three filters used in these measurements were given in Annex 2.2, Part IX, Sec. 3, Chap. 2. The curve for the infrared filter (Corning No. 2404) was

taken from the manufacturer's data. The curve for the ultraviolet filter was composed from manufacturer's data for the Corning No. 9863 glass and measured data for the $NiSO_4$ solution. The curve for the visible filters shown by the broken line in Fig. 4.3 was taken from measurements made by another laboratory prior to the selection of this filter.

Figures 4.2, 4.3, and 4.4 give the transmission curves of the three types of filters from measurements made on filters picked at random from those used in the field test. The transmission curves for the ultraviolet and infrared filters agreed satisfactorily with the curves given previously. However, there was a marked difference between the curves for the visible filter made in the pre- and post-test periods, as shown in Fig. 4.3. The final measurements showed considerable transmission by the "visible" filter in the infrared. As a result of this overlap, the sum of the measurements made behind the visible and infrared filters was greater than the total energy measurement. No energy was measured behind the ultraviolet filter.

An attempt was made to deduce the temperature of a black-body radiator, which would give the spectral distribution indicated by these measurements. The results were inconclusive but indicated that a radiator with a single temperature does not correspond with these measurements. If the spectral distribution of the radiation from the bomb were known, the measurements given could be compared with the relative amounts of energy that should have been passed by each of the three filters. This information was not available to this laboratory.

Figure 3.2 shows a discrepancy between the extrapolated and measured values of total energy at Stations 75 (Site E) and 76 (Site S). This discrepancy was emphasized by the results of the burns on the animals, which showed a continuous decrease in severity as the distance from the bomb increased.

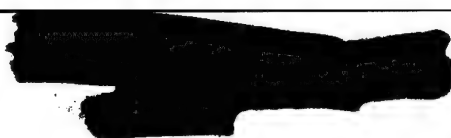A considerable dust cloud was raised by Shot Easy. One would expect that this would cause a masking effect, especially at the closer stations. If this dust cloud blocked out the lower portion of the fireball, one would anticipate that its effect would be greatest nearer the bomb. Figure 3.2 indicates this in the case of the first two stations.

In order to obtain a somewhat more quantitative idea of the effect of the dust, access was obtained to the motion-picture film of the structures program. That portion of the film recording the fate of Building 3.3.3 (Site S) was chosen and the photographic density of a particular point on the building was measured. The camera which took these pictures directly faced the front of the building. Using this calibration given for the film, these density readings were converted to relative intensity units and plotted against time. This was taken to represent the relation between flux and time at this point and is shown in Fig. 4.5.

On the same graph was plotted a theoretical curve of the flux as a function of time. This curve was taken from the Greenhouse Handbook of Nuclear Explosions, Part I,[1] and modified. It was noticed that the time of the second radiation maximum given by the curve in the Greenhouse Handbook occurred at a time greater by a factor of 2 than that time indicated by the curve obtained from the structures film. The time of the maximum from the structures film was assumed to be correct.

Prior to Shot Easy, it was learned that the fraction of the total energy of the bomb that was released as thermal energy was less by approximately a factor of 2 than had been previously supposed. Therefore, the area under the flux-time curve given in the Greenhouse Handbook should be reduced by a factor of 2. This could be accomplished by halving the time scale of this curve. This procedure brought the second radiation maximum into approximate coincidence with the peak of the curve obtained from the structures film. The resulting curve approximates the flux-time

[1] B. R. Suydam et al., Greenhouse Handbook of Nuclear Explosions, Part I (Abridged Edition), Los Alamos Scientific Laboratory (March 1951), p 169.

relation that would have been observed had there been no interference by dust. Comparison of this curve with preliminary results from another laboratory showed general agreement. This curve is given in Fig. 4.5. It was plotted on the same scale as the curve from the structure film so that the peak falls at 100. The ratio of the areas of these two curves is 0.4, whereas the ratio of the energy measured at Station 76, Site S, to the predicted energy is 0.5.

There is a marked difference in the character of the two curves of Fig. 4.5, which would indicate that the radiation from the bomb had been interfered with in an unpredictable manner on its way to Building 3.3.3. It was assumed that a similar fate had befallen the radiation which arrived at Station 75 (Site E).

With respect to the discrepancy between the severity of the burns and the total energy measured, a possible explanation is indicated by the curves of Figs. 4.6 and 4.7. The curves of Fig. 4.6 show the flux-time relation at each station had there been no dust. Figure 4.7 gives total thermal energy that should have arrived at each station as a function of time and was obtained by integration of the flux-time curves of Fig. 4.6. The slope of these curves gives the rate at which thermal energy was delivered which may have an important influence on burn severity.

4.3 EXPERIMENTAL BURNS

4.3.1 Location of Animals

The location of stations used for Shot Easy was satisfactory since the range from charred burns to no burns was covered. However, burns were not obtained at the two most distant stations (78 and 79). It would have been better to use the same number of stations at closer intervals in order to provide a finer gradation of the burn severity as a function of distance. This would have been possible with the revised formula for the calculation of thermal flux, but it was not available when the stations were placed.

The portable station [2] (78a) used on Shot Easy was entirely satisfactory. If such stations could be constructed in advance of a test and placed at a time when the size and thermal yield of the explosion had been fixed, improved biological studies on thermal effects would be possible.

Only two of the six stations planned for Shot George were actually used because of the residual radioactivity on Site C and the operational hazards to personnel on the sandspits between Sites C and N at this shot. No loss occurred from this since the torrential rains prior to the shot resulted in a low thermal flux reaching the animals even at the nearest station. This experience clearly illustrated the futility of attempting thermal-burn experiments in wet weather.

4.3.2 Selection of Animals

In the laboratory experiments on local radiant energy burns, young white-skinned pigs proved to be the most satisfactory animals used. This was also true in the field tests. Fine gradations of color and coagulation of tissue could be readily observed in burns on these animals so that the severity of the lesion could be accurately assessed from its gross appearance. There was always difficulty in deciding the degree of injury in the dark-colored pigs except by microscopic examination. The dogs were the least satisfactory for evaluating damage either grossly or microscopically. Frequently the burns in the dog were more severe than their initial appearance indicated.

4.3.3 Skin Preparation of Animals

In the laboratory the hair of the white pigs was satisfactorily removed by clipping with power shears having an extra fine (No. 40) comb. The preparation of the skin of the animals for the field tests was unsatisfactory because most animals had a mange-like dermatitis and because the removal of hair was difficult with the coarse clippers available. The

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[2] Greenhouse Report, Annex 2.2, Part IX, Sec. 4.

dermatitis might have been due to the tropical environment, diet, or the use of salt water for washing.

For Shot George, an effort was made to improve skin preparation by using barium sulphide as a depilatory after clipping. Even this was unsatisfactory because of the increased skin irritation.

4.3.4 Anesthesia

Dial in urea-urethane injected intraperitoneally provided good anesthesia in the field. In doses of 60 mg per kilogram of body weight, this agent was satisfactory for dogs. The mortality in pigs receiving 75 mg of Dial per kilogram of body weight was somewhat greater than in the pre-test laboratory studies. This was probably due to the adverse conditions existing in the field as compared to those in the laboratory. The effect of climatic conditions was well demonstrated in Shot George, where a higher mortality occurred at a time when pigs were exposed to cold, wet weather.

In laboratory studies carried out since publication of the preliminary anesthesia report,[3] it was found that 70 mg of Dial per kilogram of body weight gave a significantly lower mortality than the 75-mg dose used in the field. The larger dose was employed for the test because of the long time interval betwen positioning of the pigs and their reclamation. In the laboratory 70-mg doses provided satisfactory anesthesia for over 12 hr. If animals could be reclaimed within this period in future tests, the smaller dose could be used and a lower anesthetic mortality should result. The field experience demonstrated the importance of basing the dose of anesthesia on the animal's fasting weight since many animals lost over 10 per cent of their body weight after a 24-hr fasting period. In spite of its drawbacks, the use of Dial made prolonged anesthesia for the field experiment possible.

4.3.5 Pathology of Burns

The lesions produced in the white pigs in the field were identical to those seen in the laboratory from application of high-intensity radiant energy from the carbon arc or burning magnesium. The dry, coagulated surface without much edema, cyanosis, or weeping of serum was the same. In the severe burns the character of the central carbonization and peripheral white ring surrounded by hyperemia was exactly like that produced by the carbon arc. In all grades of severity from a mild hyperemia to a char the burns produced by the bomb explosion duplicated those from the laboratory. The clinical course and healing by sequestration of the eschar were similar. They were unlike low-temperature contact burns, which were variable in depth and edematous in their early stages.

Histologically these burns also resembled those produced in the laboratory by radiant energy for they had the striking demarcation laterally and in depth that has been described as characteristic of the flash burn.[4] The injury penetrated uniformly to a horizontal line, where there was abrupt demarcation between living and dead tissue. The healing of pig burns of all grades of severity was like that of similar burns created from laboratory sources. In both, the coagulated surface formed a tough eschar which appeared to seal the damaged area. Epithelium grew from the intact hair follicles and proliferated under the eschar to cover the injured surface just as it did in the experiments reported[5] on burns from magnesium. The eschar then sequestrated leaving an epithelialized surface. The dog has not been used as much as the pig in the laboratory experiments on radiant energy burns, so comparisons were more difficult in this animal.

These experiments demonstrated, for the first time, the pathology, both gross and microscopic, of the thermal burn from the atomic bomb in animals. They showed that in the pig this was a lesion closely resembling the laboratory radiant energy burn. This confirmed the validity of the observations made

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[3] Greenhouse Report, Annex 2.2, Part IX, Sec. 2.

[4] Greenhouse Report, Annex 2.2, Part IX, Sec. 1.
[5] *Ibid.*

in the laboratory and opened the way to further experimentation.

4.3.6 Relation of Energy to Burns

All past experience led to the conclusion that the severity of burns was proportional to the intensity of the thermal exposure and the time of its application. At Station 75, Shot Easy, all the animals had charred burns. In laboratory studies with the 24-in. arc, 21 cal/cm^2 for a 1-sec exposure was required to produce carbonization on the white pig. The degree of carbonization seen in the animals at Station 75, Shot Easy, was greater than this threshold level. Carbonization of this degree was encountered only when using 34 cal/cm^2 in a 1-sec exposure with the 24-in. arc or with 30 cal/cm^2 in 0.33 sec with the 60-in. arc. This would lead to the assumption that the carbonization seen on the surface of these burns required at least 30 cal/cm^2 in 1 sec or less. Little was known about the relation of the rate of delivery of radiant thermal energy and the severity of the resultant burn. Following the field tests, preliminary experiments done in the laboratory indicated that a more severe burn occurred when an amount of energy was delivered in 0.1 sec than when the same amount was applied in 1 sec. To date it has not been possible with the present equipment to carry these experiments to the threshold of carbonization.

The animals at Station 76, Shot Easy, received 3+ and 2+ burns. Threshold studies in the laboratory showed that with a 1-sec exposure 8.5 cal/cm^2 was required to give a uniformly coagulated surface of a 3+ burn and 5.5 cal/cm^2 was needed to produce the spotty coagulation on the surface of a 2+ burn. From these data, the burns at 2,270 yd from 50 kt would be assumed to result from between 5.5 and 8.5 cal/cm^2 in 1 sec or less.

The burns in six white pigs received through unmodified ports at 3,109 yd in Station 77 were graded 1+ in three, and 2+ in three. In the laboratory 3 to 5.5 cal/cm^2 in 1 sec was required to produce similar lesions.

There were seven white pigs at 3,500 yd in Station 78, all of which had 1+ burns. These lesions were comparable to the burns in the laboratory caused by 3 to 4.5 cal/cm^2 in 1 sec.

Using the laboratory values as a standard, the burns in the white pigs were caused by a range of energy from 30 cal/cm^2 at 1,325 yd to 3 cal/cm^2 at 3,500 yd delivered in 1 sec or less. But the instrumental measurement of total integrated energy gave considerably lower values at the first two stations, while those at the more distant ones correlated well with the laboratory data. The reasons for this discrepancy were not apparent.

4.3.7 Effect of Skin Color on Burn Production

The reflectance of radiant energy by a white surface and its absorption by a black body were strikingly demonstrated by the difference in severity of the burns of dark pigs when compared to those of light ones at Stations 76 and 77, Shot Easy. The gray or black spots on some dogs showed charring, whereas the white skin was scarcely damaged. These results may be explained by the greater transmission of energy in the infrared and its increased absorption by dark-skinned animals.

4.3.8 Spectral Effects

There was no burn produced in any animal at any station through the port which transmitted only ultraviolet light. Most of the ultraviolet irradiation was in the initial flash. However, very small amounts of ultraviolet cause skin erythema especially in the critical zone of 2,970 A, so it was significant that no burns were produced by it. This finding correlated with the absence of any burns behind the shutters that were open for only 22 msec, for it was during this period that much of the ultraviolet was released.

It was found after the test that the filters transmitting visible light had some transmission of infrared. The burns produced behind the filters transmitting the visible waves were equal to or in some cases slightly worse than

those behind the infrared filters. If the small amount of infrared were subtracted from the energy passing the visible filters, it might be assumed that the burns would have been about the same as those behind the infrared filters.

4.3.9 Time of Burn Production

No burn occurred in any animal at any station through the port that was open for the first 22 msec after the 50-kt shot or for the first 30 msec after the 250-kt shot. This was the period of the initial flash which was followed by a lull before the second maximum from the fireball. All burning occurred during the second maximum.

The slow-moving shutters which traversed 3 in. in 2 sec had apparently moved only ½ in. before all burning had ceased. It was reasoned that this traverse of one-sixth the distance meant that the burn was sustained in one-sixth of 2 sec, or ⅓ sec.

It was planned to examine the time of burning more accurately at Shot George. For this purpose, four shutters were arranged to close at from 30 to 450 msec and the slow strip shutter plate was modified by perforations which provided small burns as reference points for the shutter traverse. The adverse weather prevented the success of these efforts. However, this experience did illustrate the weakness in attempting a time resolution on a small series of animals each of which was behind a shutter with a different time exposure. When one animal died, the series was spoiled. Efforts should be made to devise a shutter mechanism that would give a resolution of several time intervals on the same animal.

It was evident that future tests should be made on the exact time the burn occurred. This information is needed not only for laboratory study but also to determine if evasive action would be of any value in preventing flash burns from an atomic bomb explosion.

4.3.10 Protective Effect of Fabrics

At Shot Easy, animals in the three most distant stations were exposed behind simple fabrics or fabric combinations. The diminished thermal yield of the 50-kt shot resulted in no burning of animals at the last two stations and such mild burns at the other that the fabrics gave complete protection. It was thought to correct this on Shot George by placing the fabrics in the nearest stations. The thermal transmission was poor on this shot, with the result that no burns occurred behind the fabrics except in one case, through sateen.

In the meantime, extensive studies were being made in the laboratory using the 24-in. arc on a study of the protective effect of fabrics. It required a large series of burns to gain accurate information on the protective effect of six fabrics.[6] This study demonstrated that the effect on the fabric could not be used as a guide to its protective effect, for 2+ burns were sustained behind fabrics that were unchanged. It also showed that there were so many variables in this type of testing that it was more suited to laboratory than to field experimentation.

4.3.11 Effect of Ionizing Radiation on Burns

Presumably the burns sustained by animals with fatal doses of ionizing radiation were too small in area to influence the mortality. A burn of larger area would be needed to test the effect on mortality of the combination of burns and ionizing radiation.

It was observed that procedures which were ordinarily insignificant might cause a fatal result in animals with severe radiation sickness. Examples of this were the production of a massive hematoma from a simple venipuncture and deaths from small doses of nembutal given to obtain biopsies.

The uninterrupted healing of severe burns in pigs dying of radiation sickness was a striking phenomenon. If the burn had progressed to a point of partial epithelialization, then

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[6] J. H. Morton, H. D. Kingsley, and H. E. Pearse, "Studies on Flash Burns: The Protective Effects of Certain Fabrics," UR 174 (Rochester, N. Y.: University of Rochester Atomic Energy Project, 1951), p. 65.

healing proceeded in spite of mortal radiation sickness. But granulating biopsy wounds or burns became gangrenous and sloughed when signs of radiation sickness appeared. This indicates that all efforts should be made to promote healing of burns and that all definitive surgery should be done early in those who have received significant amounts of ionizing radiation. More observations will be required to confirm this.

Chapter 5

Summary and Conclusions

1. The thermal-burn experiments consisted in the exposure of 82 animals behind clear quartz, timing shutters, filters, and fabrics in eight stations located at different distances from a 50-kt and a 250-kt atomic explosion.

2. The design and performance of the stations, their ventilation, wiring, control system, animal containers, and aperture plates proved satisfactory for the purposes of the test. Experience with their use led to some suggestions for improvement in the future.

The location of the stations covered the range from charred burns to no burns. The revised formula for the calculation of thermal flux, now available, should assist in more accurate placement of thermal stations in future tests. The portable station used in Shot Easy worked well and can be recommended for future use.

Only two of the six stations planned for Shot George were actually used because of the operational hazards of working on some of the sites selected. The low thermal flux which reached these stations illustrated the futility of doing thermal-burn experiments in wet weather.

3. Radiation calorimeters were designed and placed in each station to measure the total integrated energy and that passing through limiting filters. These instruments worked well. The values obtained at the first two stations on Shot Easy were lower than anticipated. At all other stations they correlated well with the expected yield and with the severity of the burns produced in the animals. This discrepancy at the two forward stations was thought to be due to some extrinsic factor and not to any fault in the instrument.

This radiometer measured only total integrated energy. It would be desirable in the future to perfect an instrument which would also give a resolution of the time of application of the energy.

4. Pigs, both black and white, and dogs were used as test animals. The white pigs proved the most satisfactory since fine gradations of color or coagulation were readily detected on their skin but not on that of the other animals.

5. Operational requirements made it necessary to place the animals in the stations the day before they were exposed. Hence, a long-acting anesthetic without explosive hazards was necessary to ensure anesthesia at the time of burning. Dial in urea-urethane injected intraperitoneally was satisfactory for this purpose.

6. The animal lesions have demonstrated, for the first time, the characteristic gross and microscopic pathology. These lesions resembled those from laboratory radiant energy sources.

7. In the laboratory, values of energy from the carbon arc have been obtained for causing burns of different degrees of severity in the white pig. Using these values as a standard, the burns from the 50-kt source in the white pigs were produced by a range of energy from 30 cal/cm^2 at 1,325 yd to 3 cal/cm^2 at 3,500 yd, delivered in 1 sec or less.

8. No burns were produced in any animal through the filter transmitting only ultraviolet light.

9. The burns received behind filters transmitting visible and infrared rays were about equal in severity. Dark-colored animals generally had a deeper burn than white ones.

10. No burn was produced in the first 22 msec after a 50-kt shot or in the first 30 msec after a 250-kt shot. All burning occurred in the first 0.5 sec of the second maximum. Efforts to define more accurately this time at Shot George failed, hence this should be done at future tests. This information is needed not only for laboratory investigation but also to assess the value of evasive action.

11. No information was obtained from a study of the protective effect of fabrics in these field tests. This type of experimentation is done better in the laboratory.

12. Burns or wounds that had reached the stage of epithelialization healed in spite of fatal radiation sickness but in a few cases those which were open and granulating became gangrenous. Further observations are needed to confirm this, for cases subjected to radiation and trauma may require early definitive surgery.

13. The most important attainment of the thermal-burn experiments in the field was the acquisition of data to confirm and advance laboratory investigations.
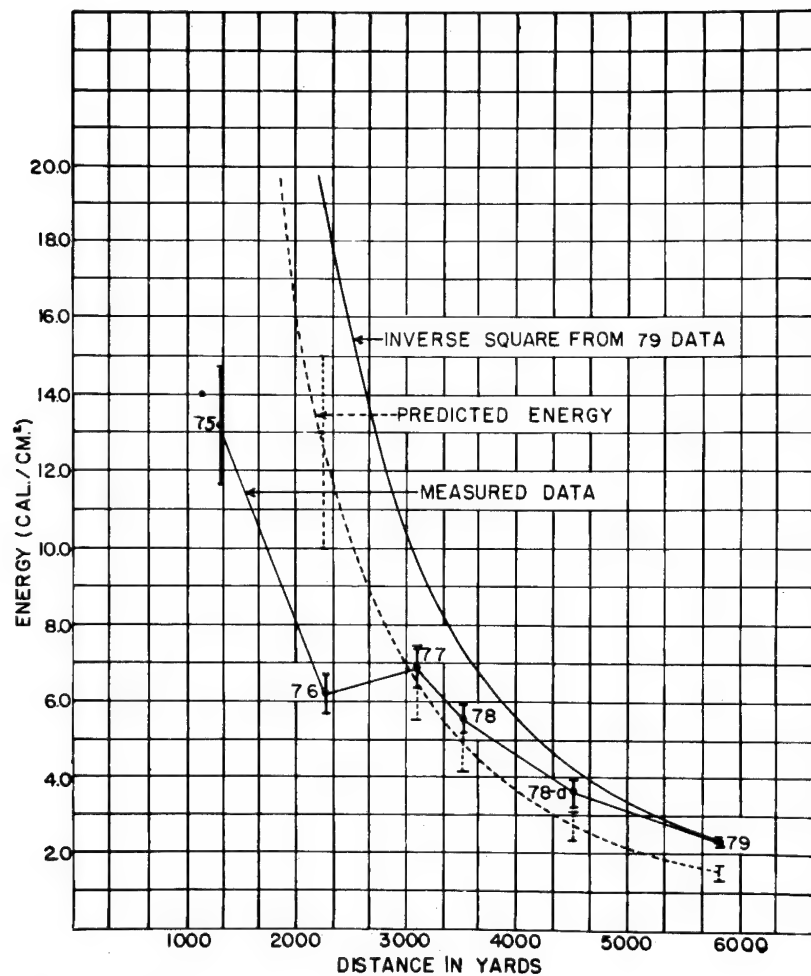
FIG. 3.1 Predicted and Measured Values of Total Energy at Thermal
Stations for Shot Easy
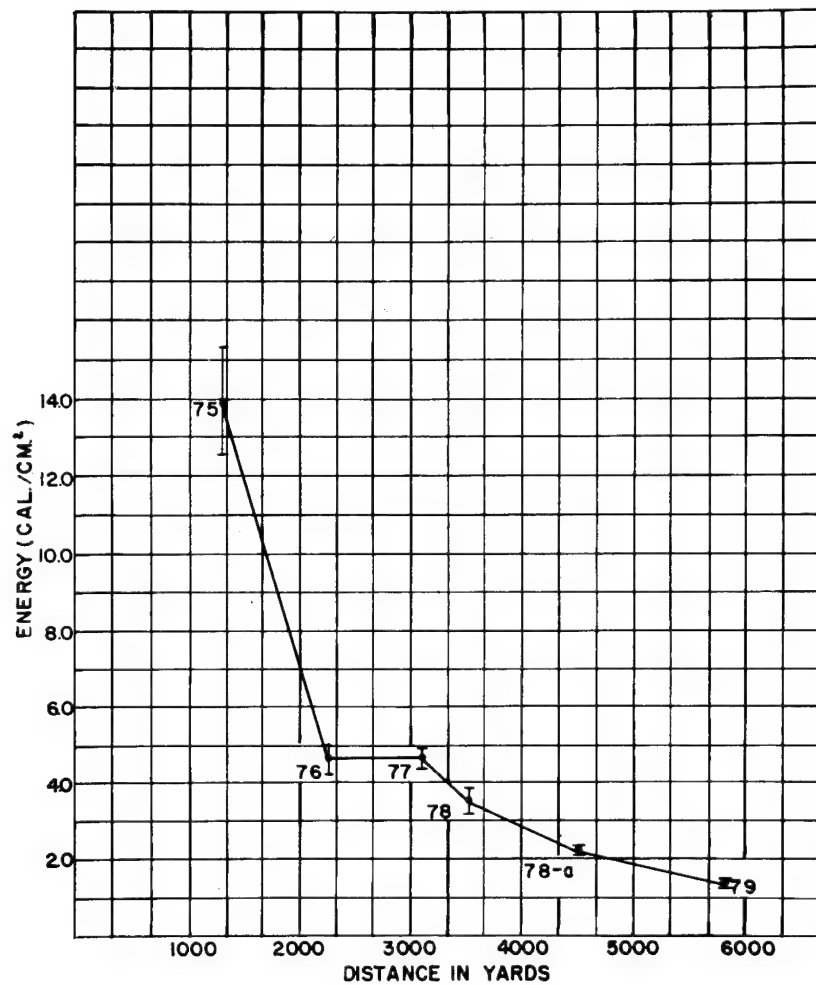
FIG. 3.2 Measured Data behind Visible Filters at Each Thermal
Station for Shot Easy
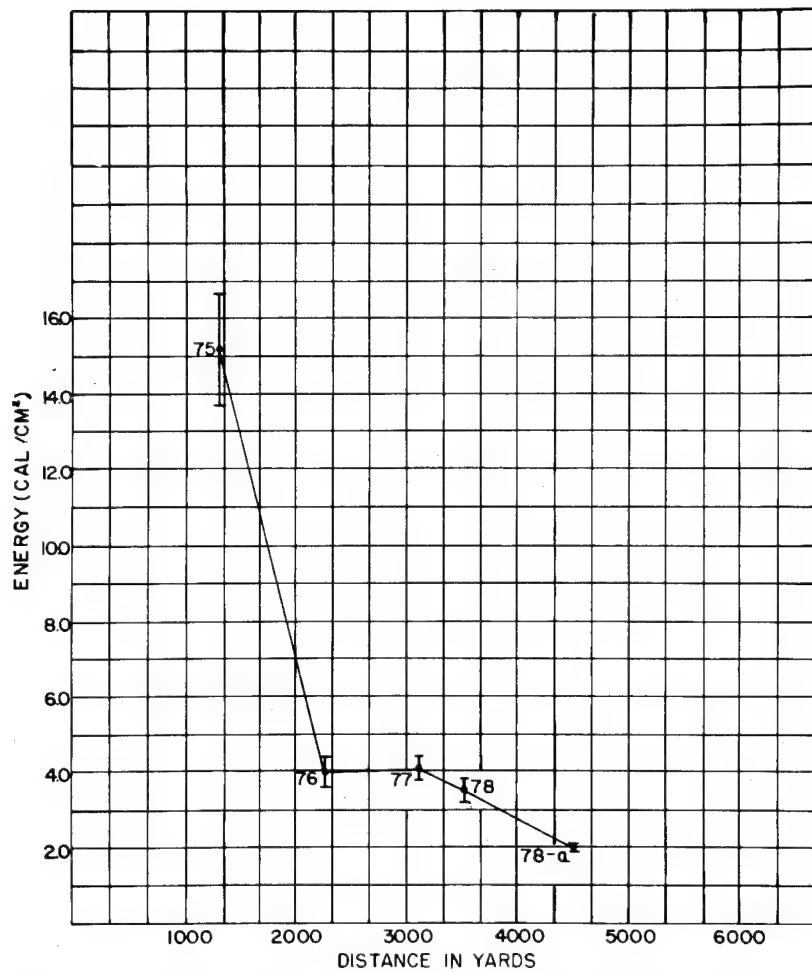
FIG. 3.3   Measured Data behind Infrared Filters at Each Thermal
Station for Shot Easy
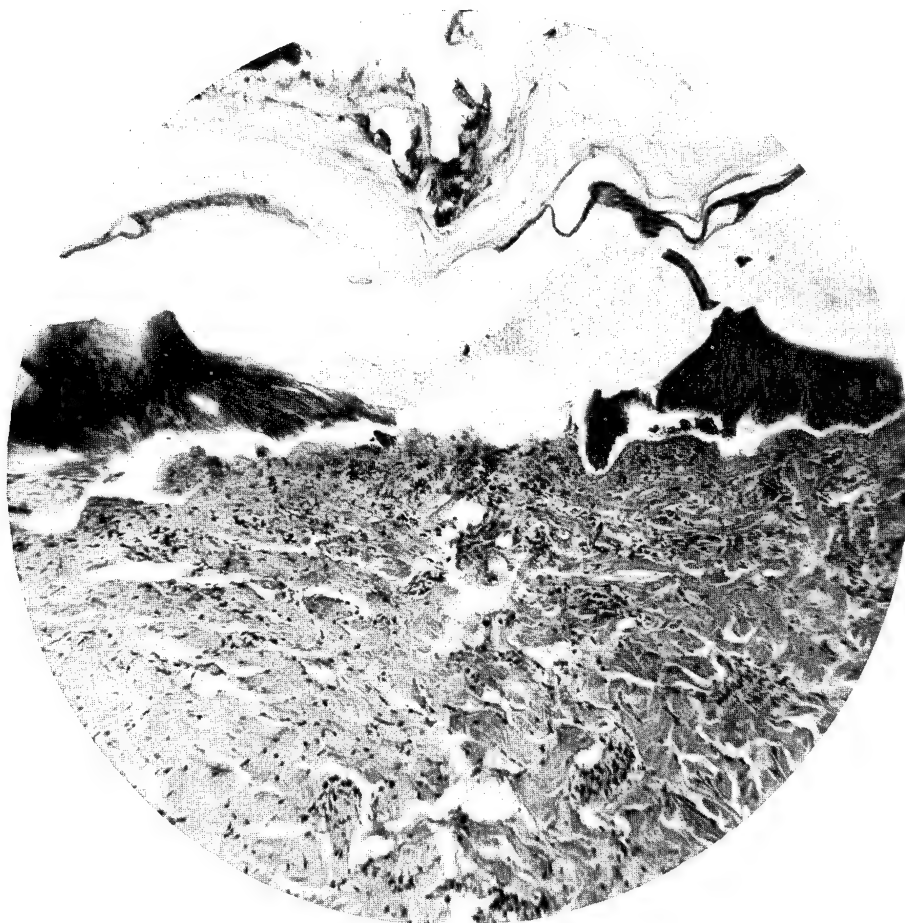
FIG. 3.5 Section (X65) of Chester White Pig 270 at 1,325 Yd 13 Hr after Exposure to 50 Kt. There is coagulation and destruction of the epidermis but no obvious demarcation of the depth of the burn in the dermis.
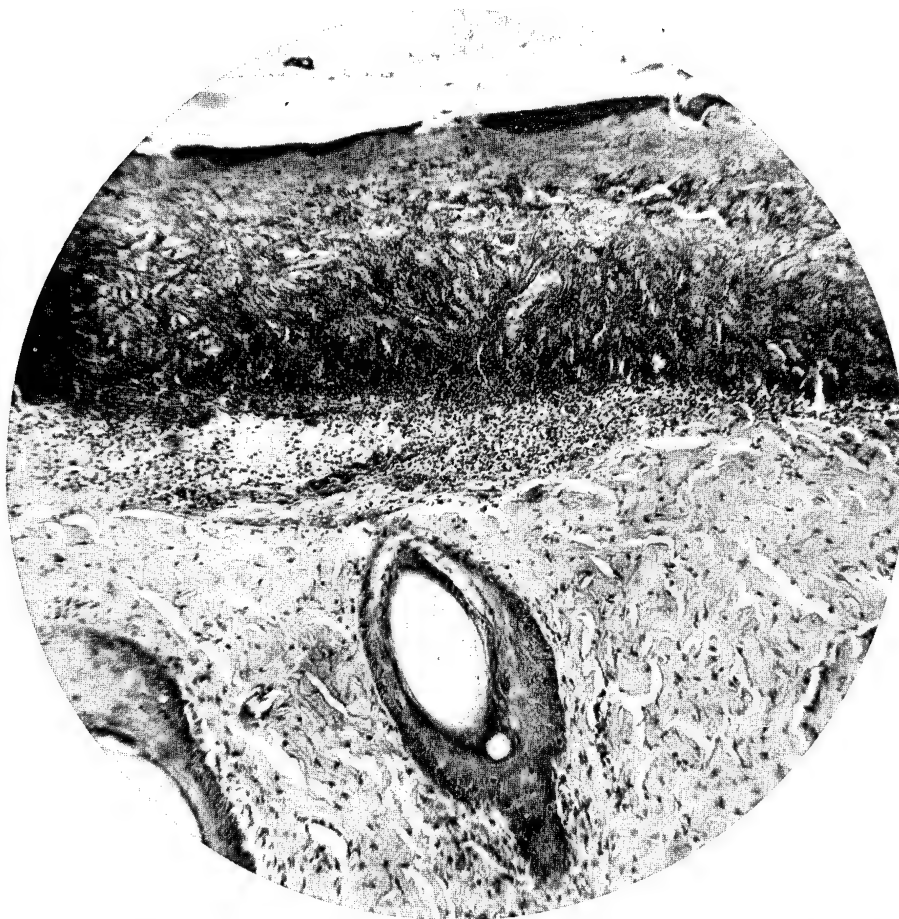
FIG. 3.6 Section (X65) of Danish Landrace Pig 269 at 1,325 Yd 74 Hr after Exposure to 50 Kt. The line of demarcation in depth is indicated both by the basophilic staining of the burned dermis and the inflammatory reaction between living and dead tissue.
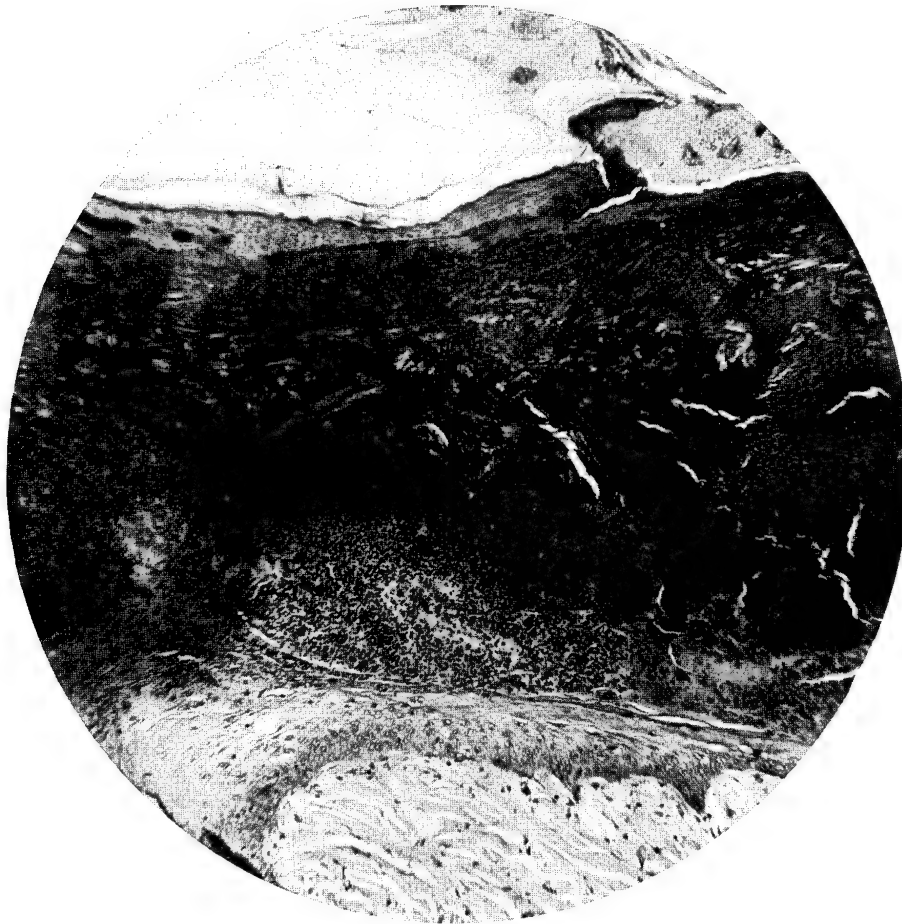
FIG. 3.7 Section (X65) of Chester White Pig 270 at 1,325 Yd 122 Hr after Exposure to 50 Kt. A wedge-shaped layer of epithelium has grown out of the hair follicle in the lower left corner and is proliferating under the thick eschar.
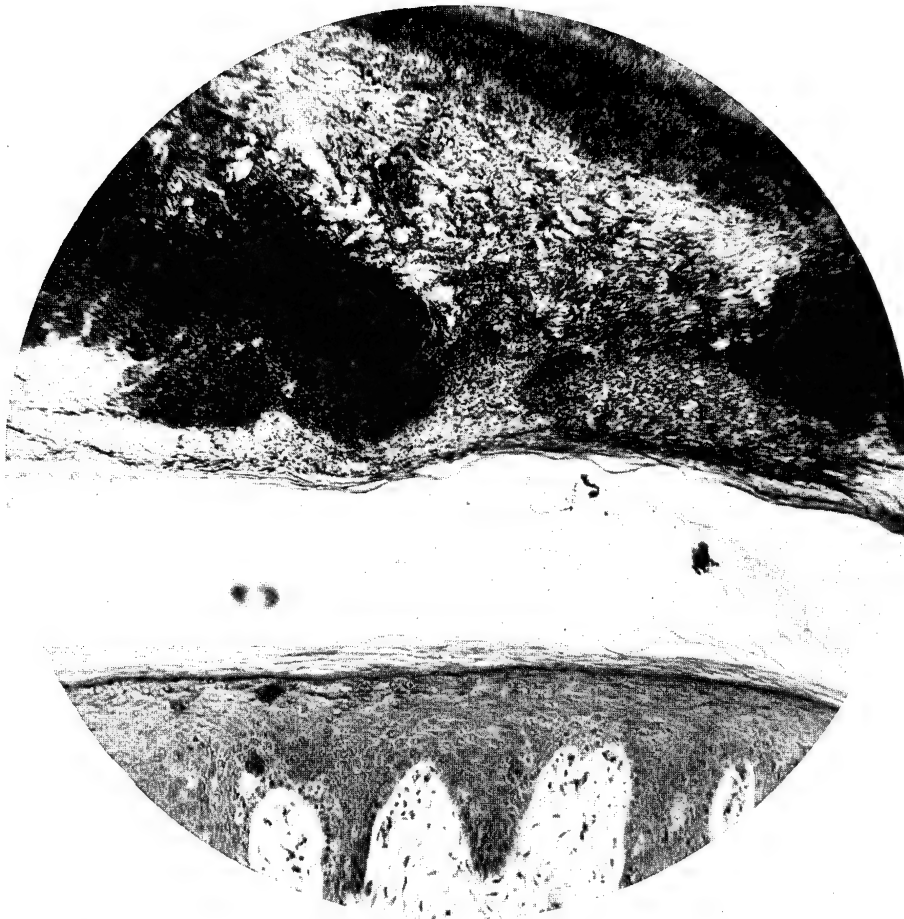
FIG. 3.8 Section (X65) of Danish Landrace Pig 269 at 1,325 Yd 228 Hr after Exposure to 50 Kt. The new epidermis has completely regenerated beneath the eschar which has separated in this location, but is loosely attached elsewhere. At this stage, the eschar may be easily pulled off, exposing a healed surface beneath.

Fig. 3.9　A 4+ Burn in Danish Landrace Pig 268 at 1,325 Yd from
Shot Easy 360 Hr (15 Days) after Injury, Showing Shedding Eschar
with Underlying Healed Depigmented Epithelium
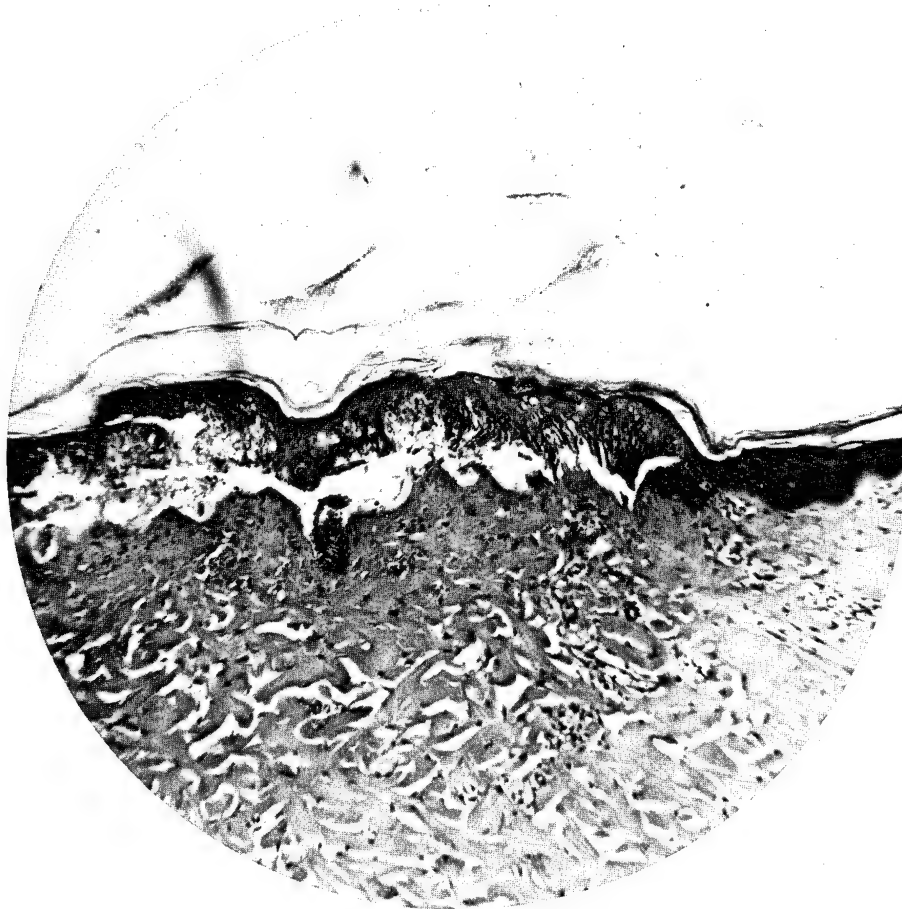
FIG. 3.11 The Transepidermal Injury in Danish Landrace Pig 256 Is Shown 14 Hr after Exposure to 50 Kt at 3,109 Yd in Station 77. The sharp lateral demarcation of the injured and normal epidermis is well shown. There is no obvious demarcation in depth at this stage (X65).

FIG. 3.12   Section (X65) from Danish Landrace Pig 255.   At 74 hr after burning the injured dermis has a blue basophilic staining which contrasts with the red eosinophilic stain of the normal dermis.   This delineates the uniform depth of the thermal damage which is characteristic of some flash burns.
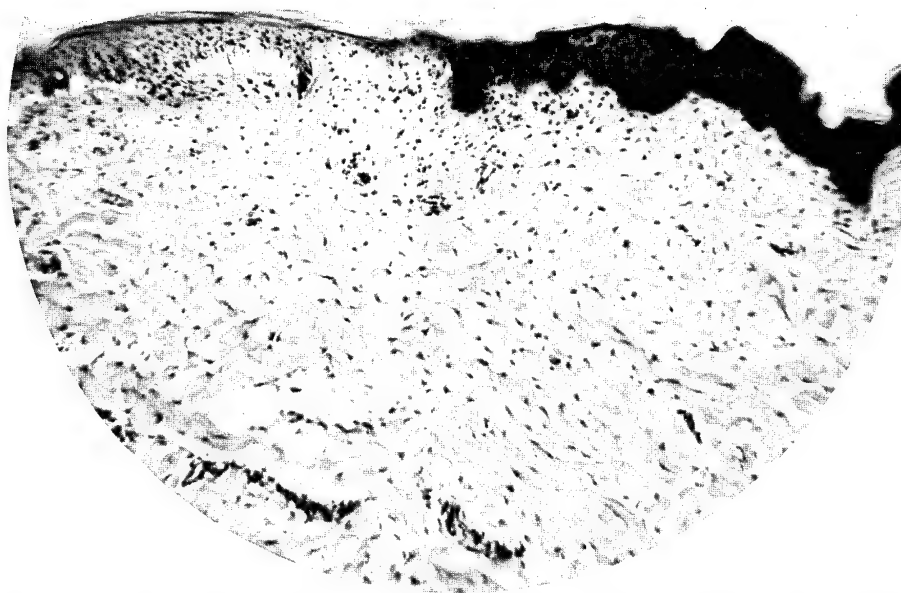
FIG. 3.14 The Transepidermal Injury in Chester White Pig 224 15 Hr after Exposure at 3,109 Yd in Station 77 from 50 Kt. In the center is seen the sharp demarcation between injured and uninjured epidermis.

FIG. 3.15 Complete Re-epithelialization of the Burn in Chester White Pig 224, 123 Hr after Exposure to 50 Kt at 3,109 Yd in Station 77. The healing about a hair follicle is shown.
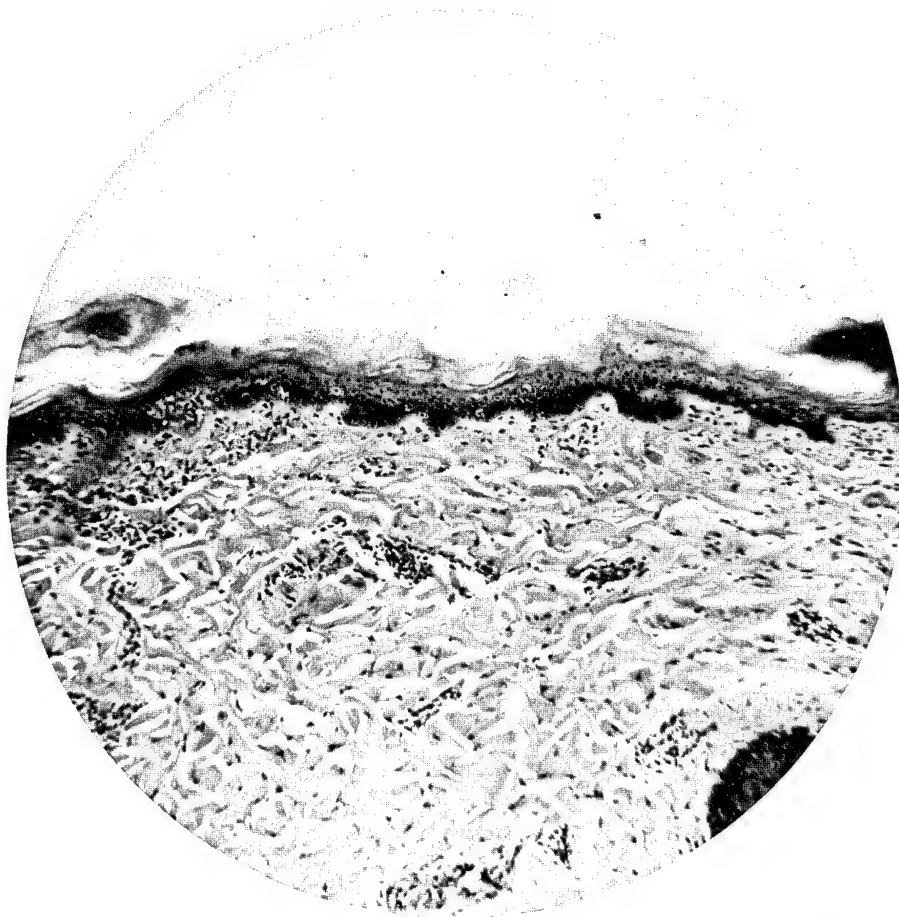
FIG. 3.17 A 1+ Burn in Chester White Pig 337 Seen 11 Hr after Exposure to 250 Kt at 4,785 Yd in Station 76 of Shot George. There is only partial epidermal injury, with normal staining of the basal layer and papillae in most areas.
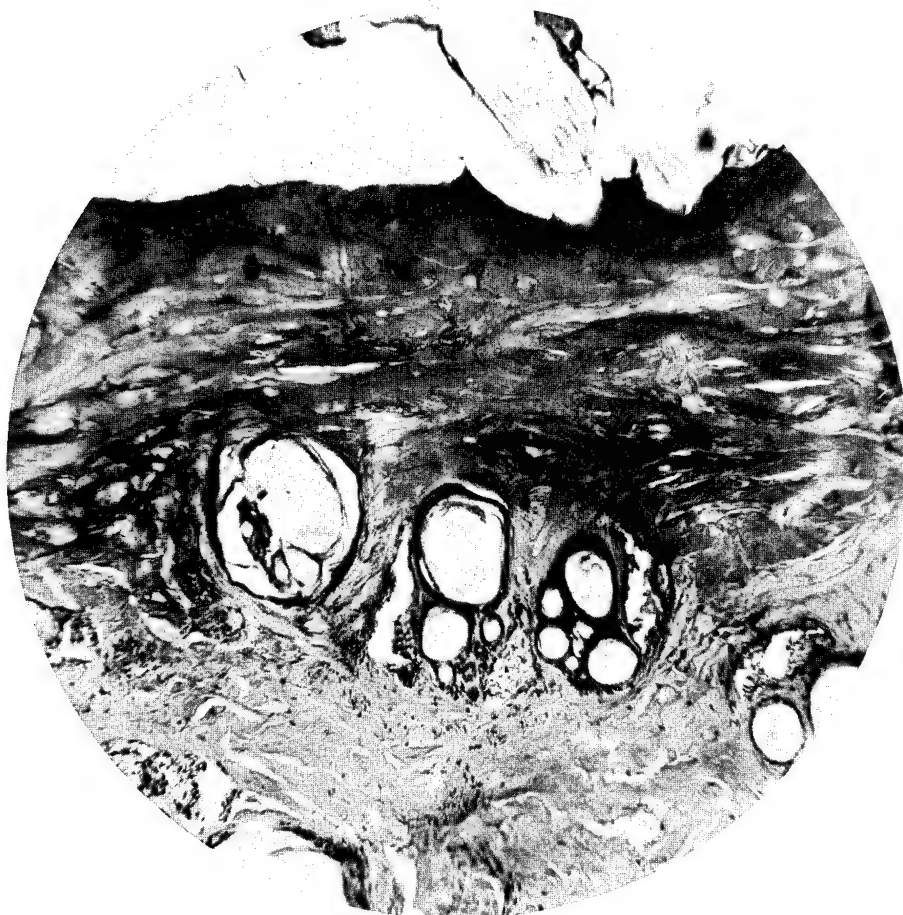
(a)

FIG. 3.18   See facing page for legend.
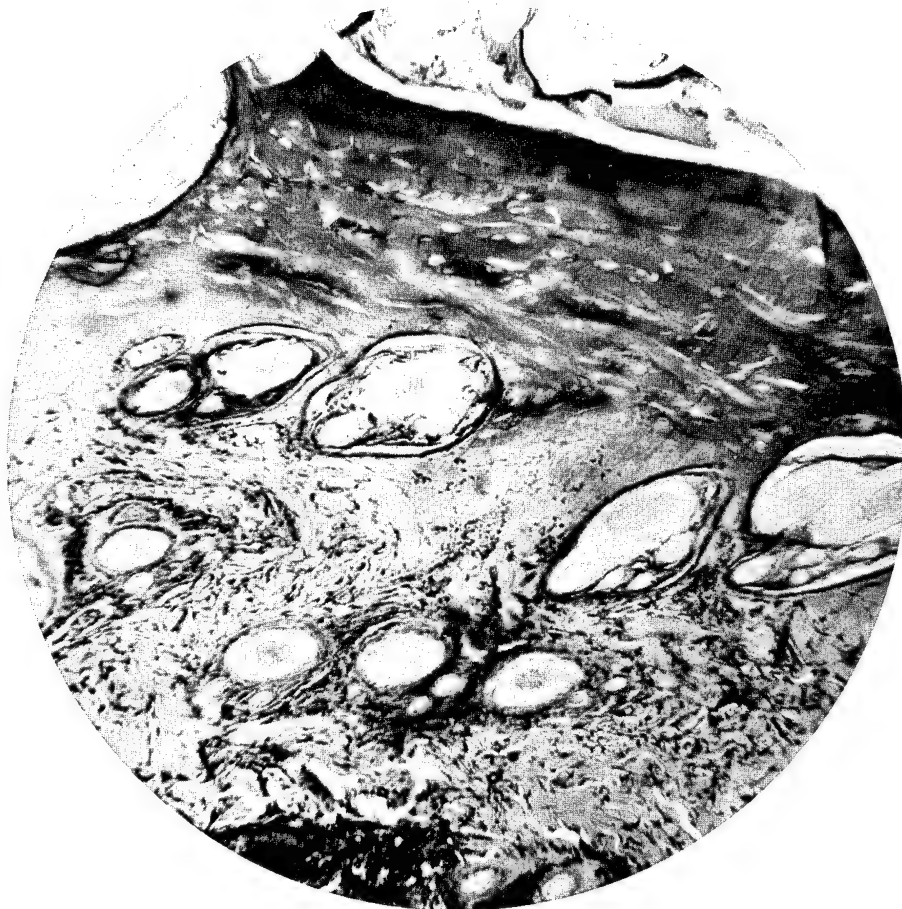
(b)

FIG. 3.18   Section (*X*65) of Dog Burn at 1,325 Yd at 12 (a) and 124 (b) Hr after Exposure to 50 Kt. It is evident that the degree of injury and depth of burn are more difficult to evaluate in the dog than in the pig.
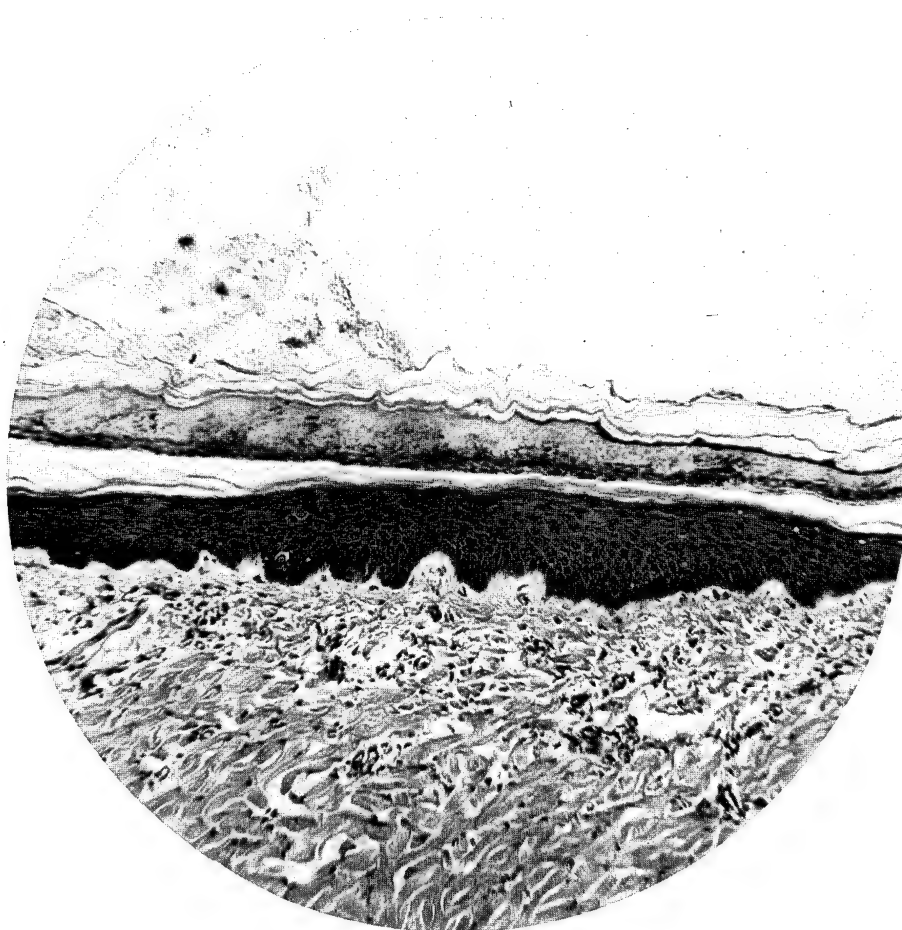
(a)

FIG. 3.19　See facing page for legend.
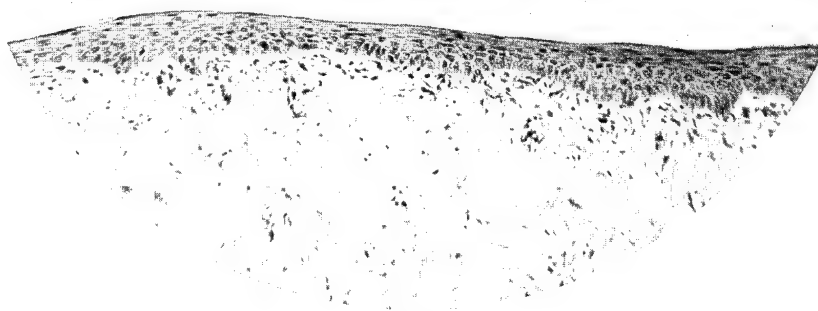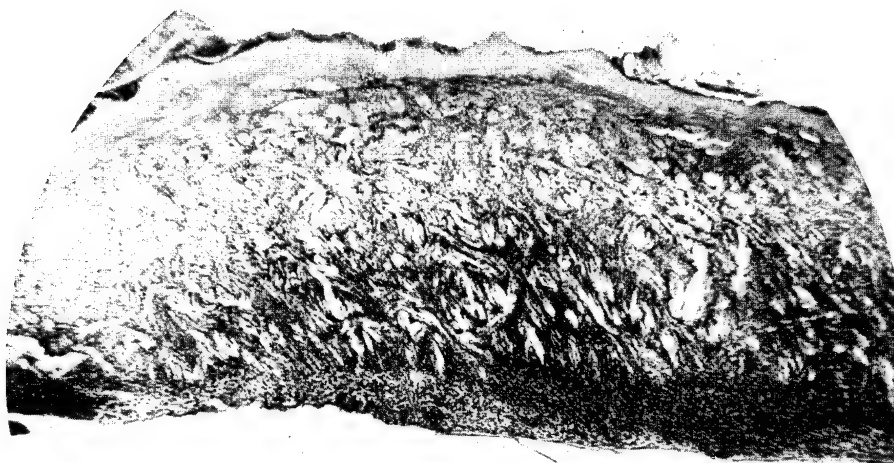
(b)

FIG. 3.19 A Comparison of Depth of Injury as Indicated by the Thickness of the Eschar at 124 Hr in (a) White Pig 202 and (b) in Black Pig 207, Both with the Same Exposure from 50 Kt at 2,270 Yd in Station 76 (X65). Restoration to normal epidermis is also more advanced in the white pig.
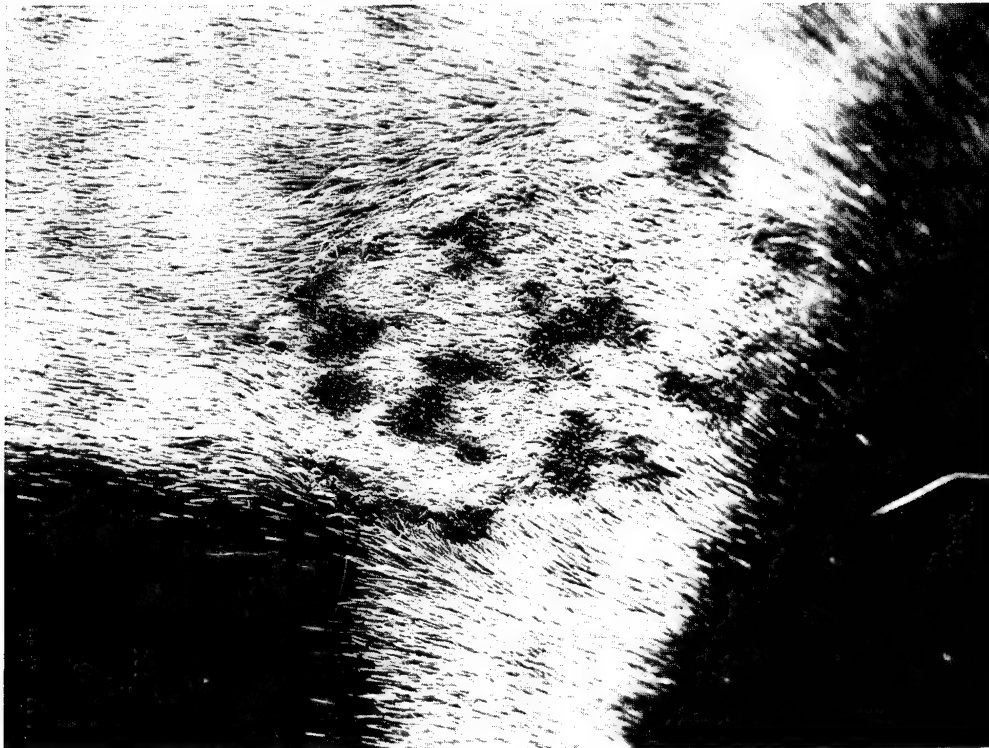
FIG. 3.20 Effect of Reflectance of the Radiant Energy by the White Skin with Absorption and Burning of the Gray Spots through the Unmodified Port of a Quick Shutter in Dog 886 at 3,109 Yd in Station 77 on Shot Easy.   The burned areas broke down later and required 19 days to heal.
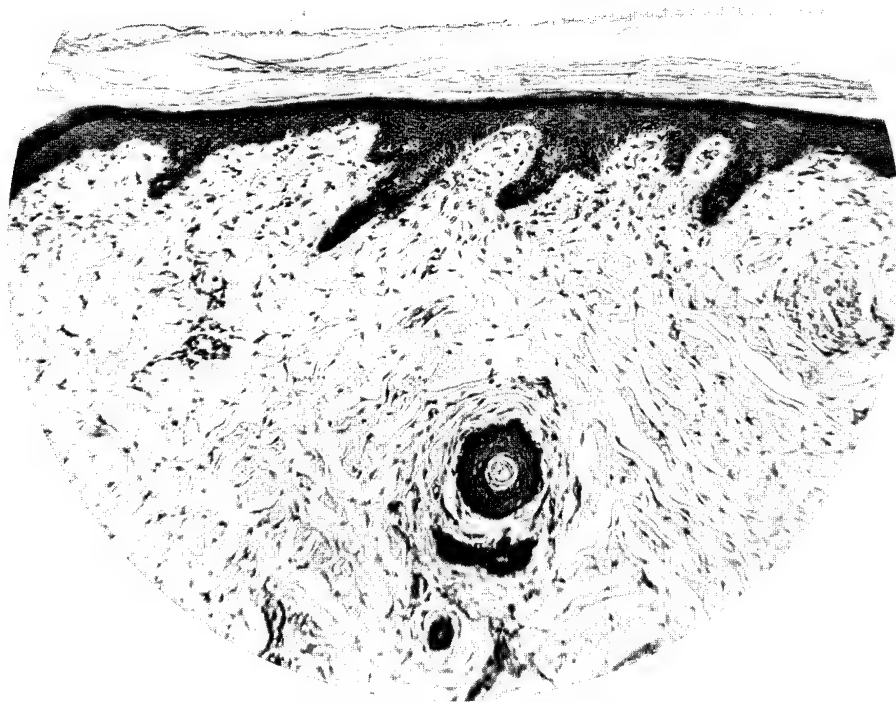
FIG. 3.21 Skin Section (X65) of Danish Landrace Pig 268 at 1,325 Yd Taken 360 Hr (15 Days) after Exposure to 50 Kt. This section was taken on the day of death from ionizing radiation. The eschar has come off and the wound is healed but-the epidermis is atrophic in appearance.
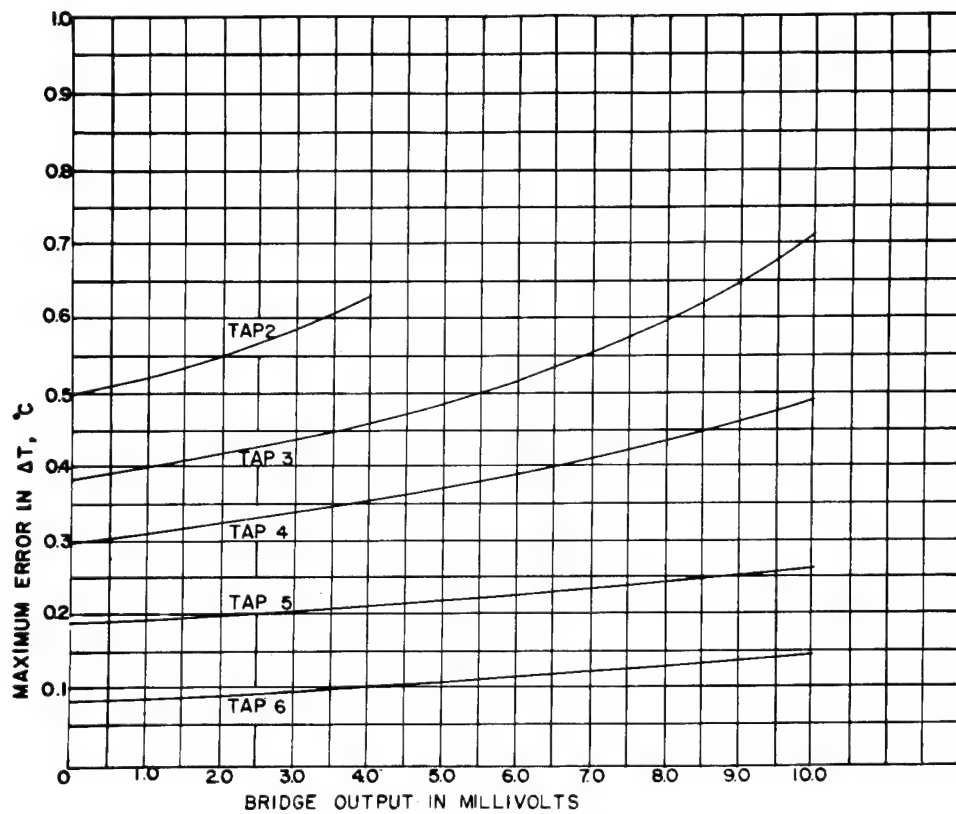
FIG. 4.1 Uncertainty in Temperature Measurement with Thermistor and Bridge Circuit as a Function of the Bridge Imbalance for the Various Sensitivity Settings
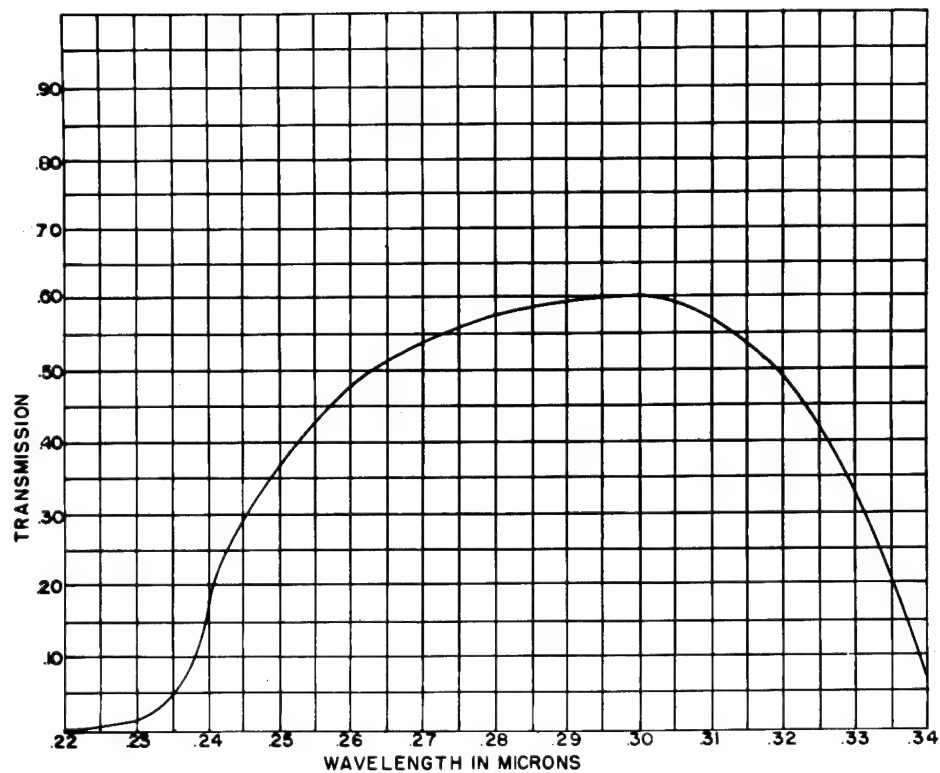
FIG. 4.2 Transmission Curve for Ultraviolet Filter as a Function of Wave Length
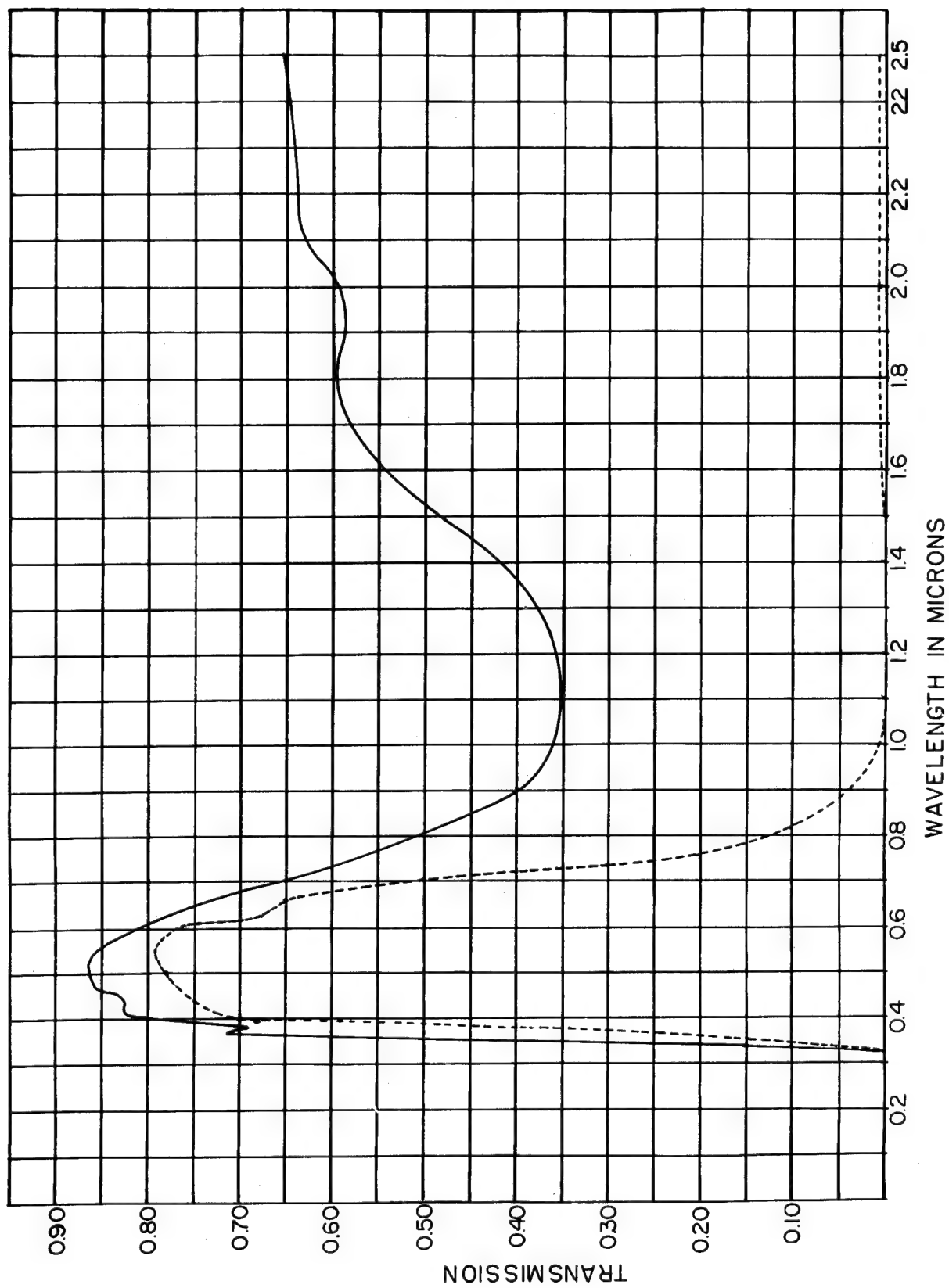
Fig. 4.3   The Dotted Line Shows Transmission Curve for Visible Filter as a Function of Wave Length Plotted from Measurements Made Elsewhere before Selecting This Filter.   Solid line shows the curve of measurements made in this laboratory after the test.

FIG. 4.4 Transmission Curve for Infrared Filter as a Function of Wave Length
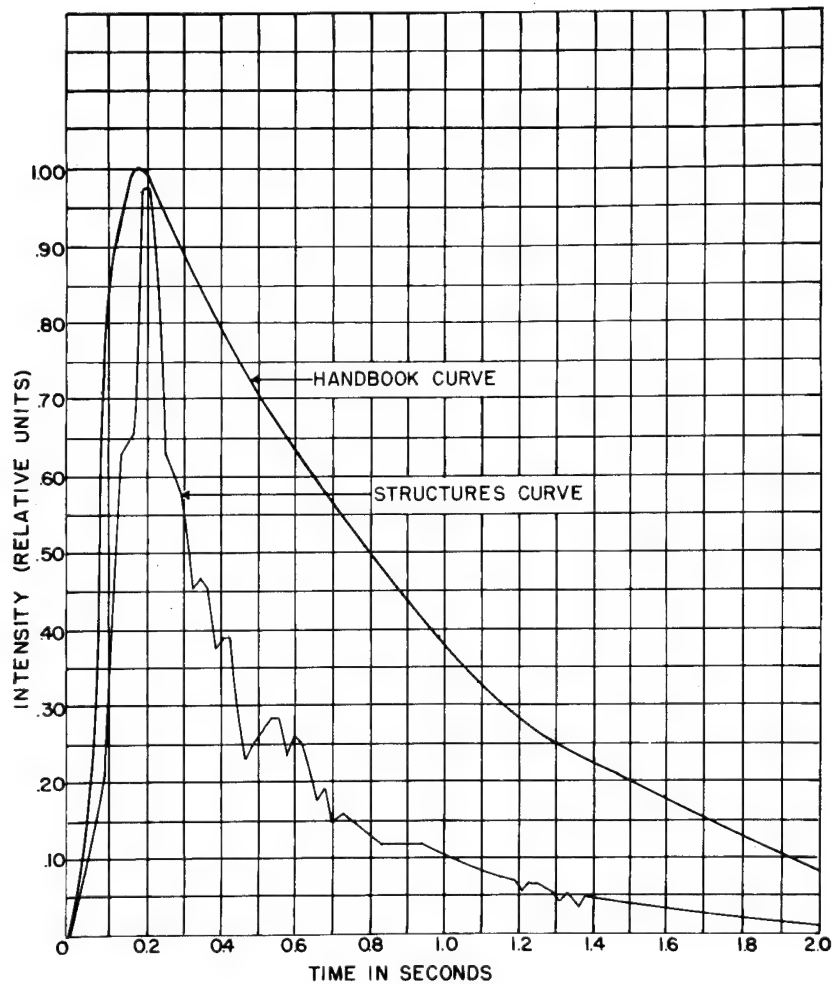
FIG. 4.5 Flux as a Function of Time at Station 76 from Data Obtained from the Structures Film and from the Greenhouse Handbook of Nuclear Explosions
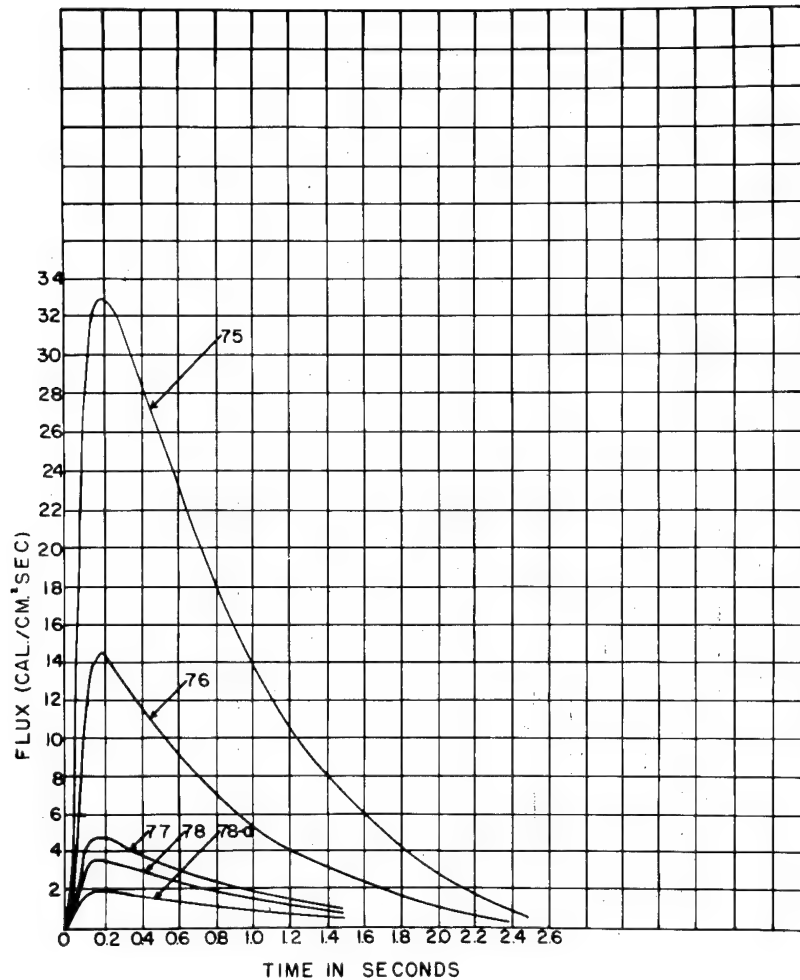
FIG. 4.6 Theoretical Flux-Time Relation at the Thermal Stations
Had There Been No Dust
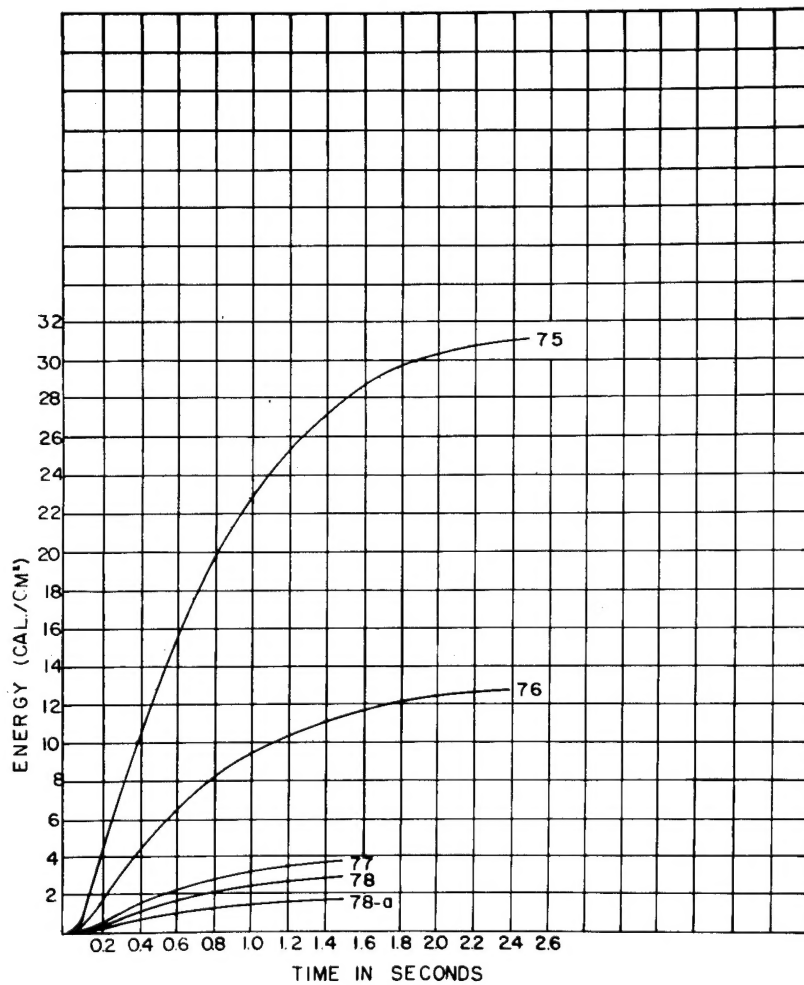
FIG. 4.7 Total Energy as a Function of Time Which Would Have Arrived at Each Thermal Station Had There Been No Dust
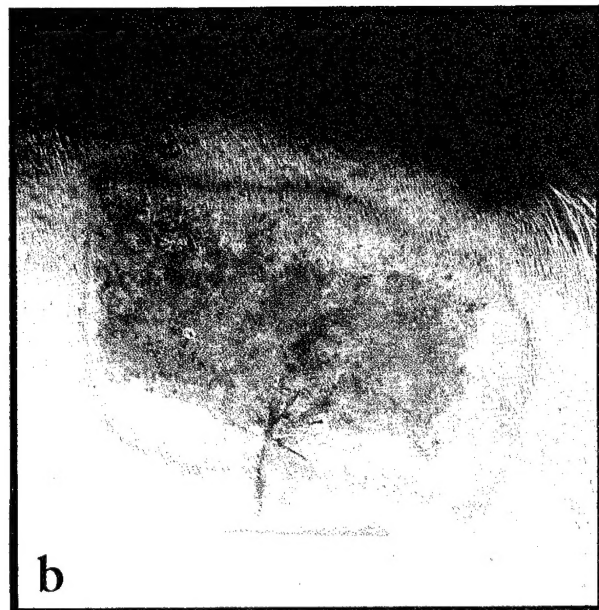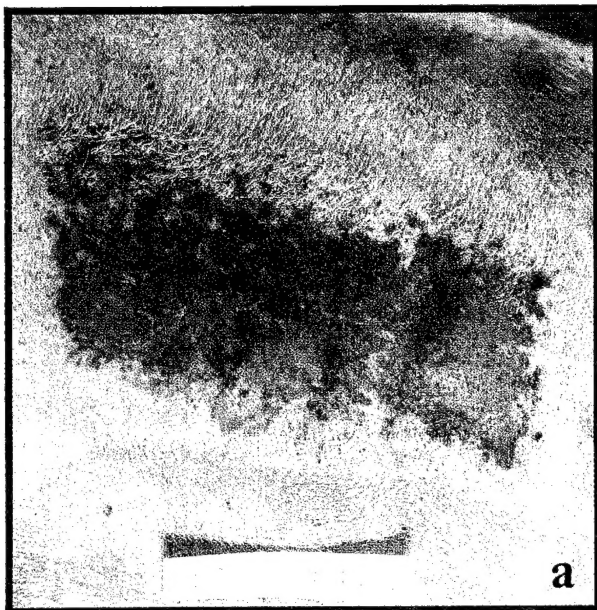
FIG. 3.4 (a) The Appearance of a Severe 4+ Carbonized Burn in Chester White Pig 265, 13 Hr after Exposure to 50 Kt at 1,325 Yd in Station 75. (b) The Same Lesion 122 Hr after Burning. Note the zone of white coagulation surrounded by a ring of erythema outside the carbonized burn.
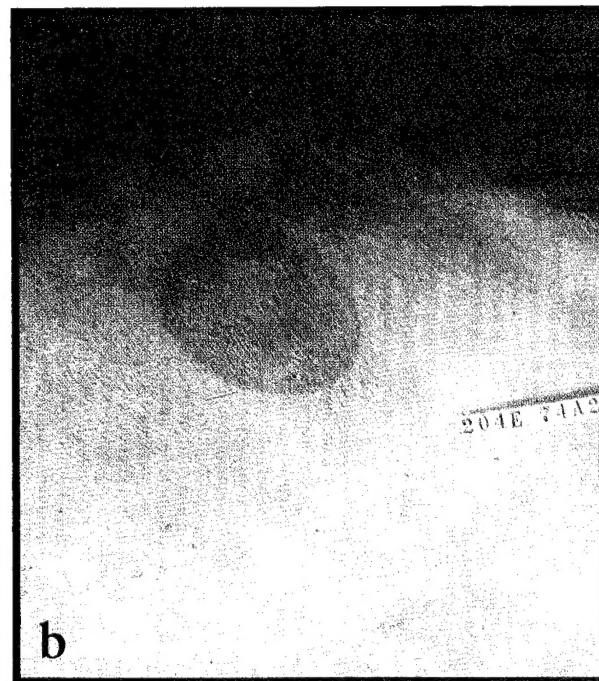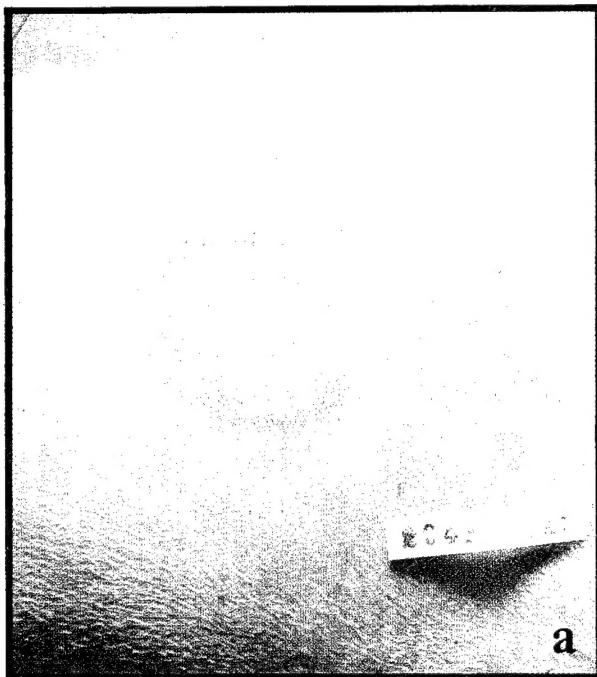
FIG. 3.10 (a) The 3+ Burn in Chester White Pig 204 11 Hr after Exposure at 2,270 Yd in Station 76, Shot Easy. Note the coagulation uniformly over the surface without charring. (b) The Same Burn 74 Hr after Injury. The lesion is now uniformly dark brown in color, dry, and sharply outlined.
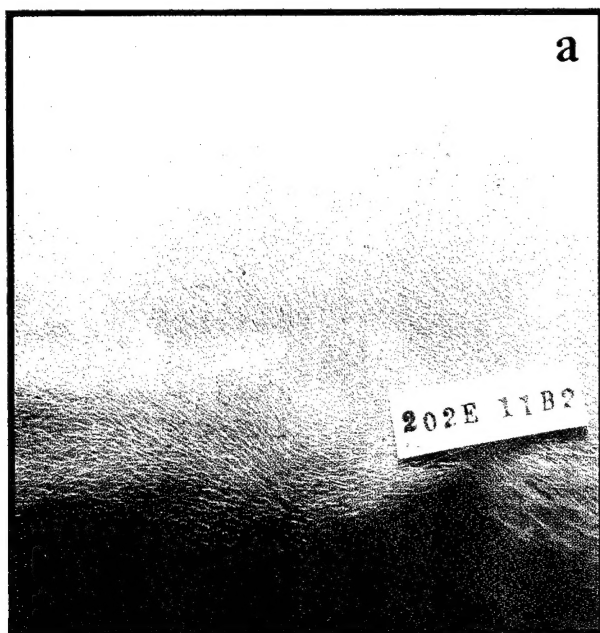
FIG. 3.13 The 2+ Burn in Chester White Pig 202 (a) 11 Hr after Exposure at 2,270 Yd in Station 76 from a 50-kt Shot, and (b) the Same Burn at 124 Hr. Spotty coagulation is seen on the surface in (a).
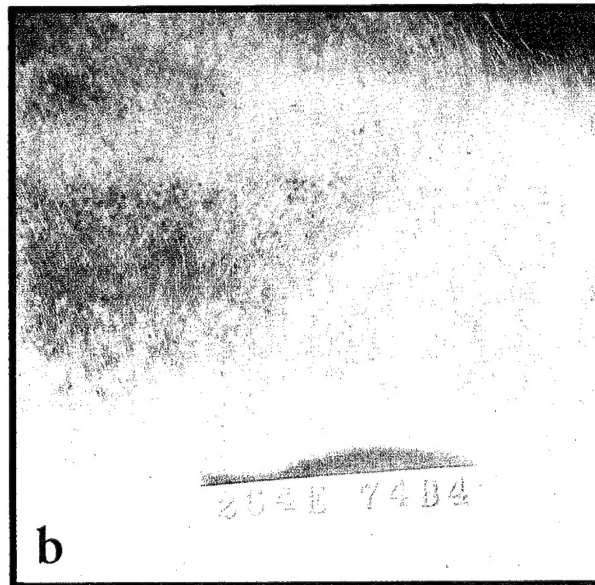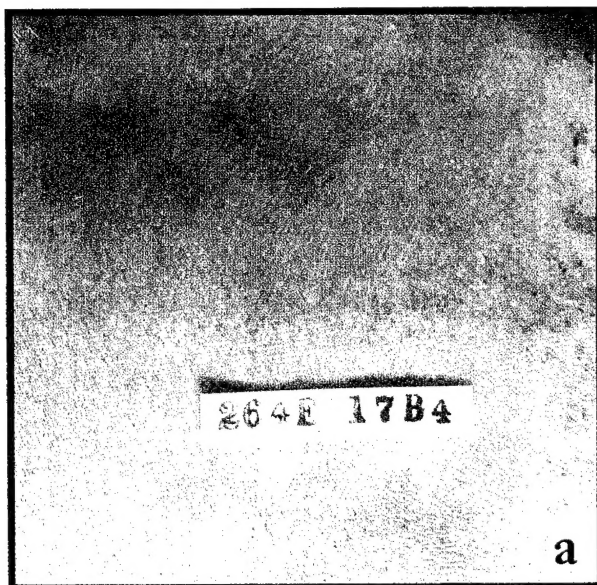

FIG. 3.16 (a) A 1+ Burn in Chester White Pig 264, 17 Hr after Exposure to 50 Kt at 3,500 Yd in Station 78. The erythema without surface coagulation appears uniform. (b) Taken at 74 Hr; the Burn Appears More Severe in the Left 2 In., Where the Shutter Was Open throughout the Exposure. The 3 in. of burn to the right of this was covered in 2 sec after detonation by the sliding shutter plate. No burn occurred to the left, where the shutter opened after the explosion.
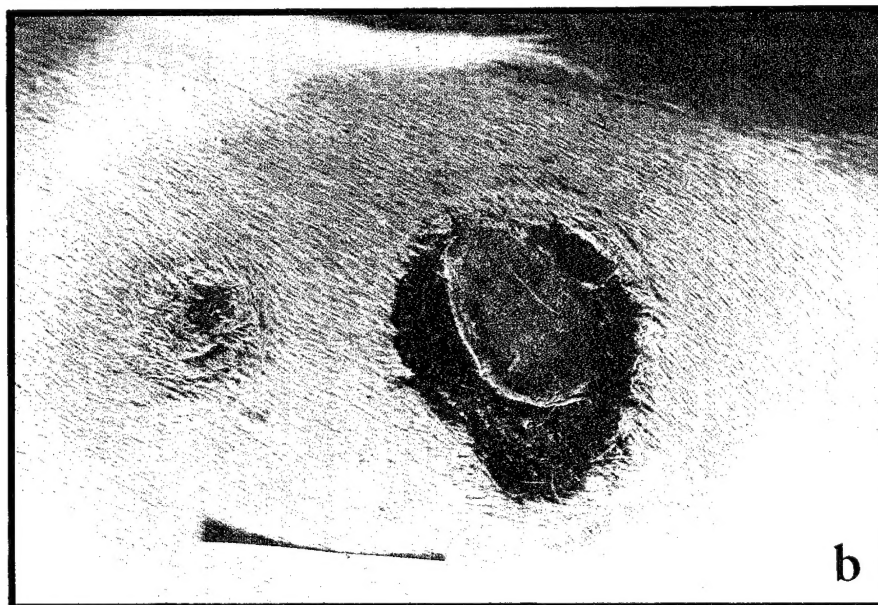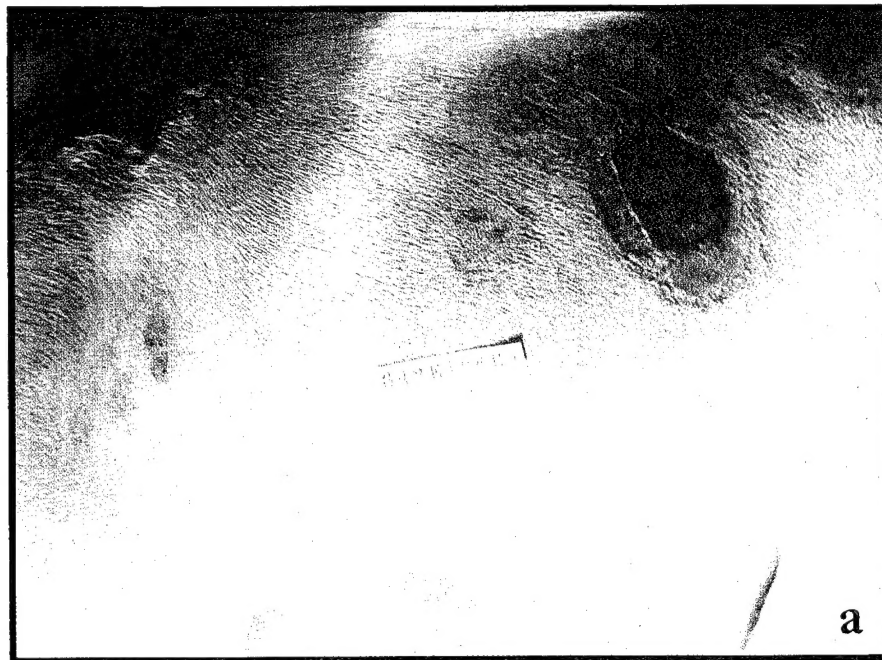
Fig. 3.22 (a) The Healthy Granulating Burn in Dog 642 Is Shown 124 Hr after Exposure to 50 Kt at 1,325 Yd in Station 75. (b) This Is Contrasted with the Terminal Gangrene of This Wound at 235 Hr, a Short Time before the Animal's Death.